THE AMERICAN
JOURNAL OF PSYCHOLOGY
Founded by G. Stanley Hall in 1887

Vol. XXVI JANUARY 1915 No. 1

THE SENSATIONS OF THE ALIMENTARY CANAL[1]

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CONTENTS

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Historical

The problem of the sensibility of the internal organs has occupied the attention of more than one physiologist. Weber[2] in 1846 performed some simple experiments, which were, however, not conclusive, because his technique was inadequate. Recent work dates from the first publication of Lennander[3] in 1901. Lennander, chiefly on the basis of clinical data, put forward the hypothesis that the internal organs, including the stomach, intestine, liver, gall-bladder, kidneys, and the intervening tissues, are entirely insensitive. Sensations that seem to occur in these organs, such as the feeling of digestion or the pain from irritation, are mediated by the parietal peritoneum. Meumann[4] opposed the theory of Lennander in an article which re-

[2] Weber, E. H., Der Tastsinn und das Gemeingefühl, Wagner's *Handwörterbuch der Physiologie,* 1846, III, 562ff.

[3] Lennander, K. G., Ueber die Sensibilität der Bauchhöhle und über lokale und allgemeine Anästhesie bei Bruch- und Bauchopererationen, *Centralbl. f. Chir.,* 28, 1901.

[4] Meumann, E., Zur Frage der Sensibilität der inneren Organe, *Arch. f. d. ges. Psychol.,* 9, 1907, 26ff.

views both Lennander's work and subsequent publications. He calls attention to the prominence of organic sensations in daily life,—in digestion, in intestinal pressure, in hunger, in the pains of flatulence, in esophageal pains, in sensations from the lungs and from the heart, in micturition, in defecation, in colic, and in internal irritation. Becher[5] later published a partially experimental study, in which he described the sensitivity of the esophagus and concluded that the stomach is insensitive. In this article he leans toward Lennander's hypothesis, in that he ascribes the feeling of vitality and other complex feelings of an organic nature to sensations from the body-wall, the pleura, the peritoneum, the diaphragm, and, probably, the esophagus. He thinks that Meumann's sensations of the stomach must have come from the body-wall. He denies sensibility to the lung tissue, the heart, and the arteries. The veins mediate pain. Meumann replies[6] that the reference to the body-wall will not explain the difference in quality of the different stomachic sensations, or the difference of all of them from pressure; that the extension of the wall is too slight to give intense sensations; that the feeling of satisfaction is obviously dependent upon the chemical state of the stomach; and that experiments of his own with spices have demonstrated the sensibility of the stomach to one sort of stimulation. He also insists on sensations from the lung tissue and the heart, and cites experimental work upon animals to show that the large intestine, stomach, mesentery, peritoneum, spleen, and blood-vessels are sensitive to pain. While the controversy between Meumann and Becher continued, Hertz, Cook, and Schlesinger[7] published in England an experimental study, which showed, among other things, the unquestionable sensibility of the esophagus to thermal and mechanical stimulation. These results agree further with those of Head, Rivers, and Sherren,[8] who cite the colon as an example of 'protopathic' sensibility. Becher repeated[9] some of the experiments of the English workers, and convinced himself of the sensibility of stomach and intestine. He thus, eventually, came into practical accord with Meumann. At the same period, Ritter[10] and Kast and Meltzer[11] explained the apparent insensibility of the internal organs, reported by Lennander, by observations and experiments which went to show that normally sensitive organs are rendered insensitive by the subcutaneous injections of cocain used in local anesthesia. Lennander's observations were based upon opera-

[5] Becher, E., Ueber die Sensibilität der inneren Organe, *Zeitschrift f. Psychol.*, 49, 1908, 341ff.

[6] Weiteres zur Frage der Sensibilität der inneren Organe und der Bedeutung der Organempfindungen, *Arch. f. d. ges. Psychol.*, 14, 1909, 279ff.

[7] Hertz, A. F., Cook, F., and Schlesinger, E. G., The Sensibility of the Stomach and Intestines in Man, *Jour. Physiol.*, 37, 1908, 481ff.

[8] Head, H., Rivers, W. H. R., and Sherren, J., The Afferent Nervous System from a New Aspect, *Brain*, 28, 1905, 99ff.

[9] Einige Bemerkungen über die Sensibilität der inneren Organe, *Arch. f. d. ges. Psychol.*, 15, 1909, 356ff.

[10] Ritter, C., Zur Frage der Sensibilität der Bauchorgane, *Centralbl. f. Chir.*, 35, 1908, 609ff.

[11] Kast, L. and Meltzer, S. J., On the Sensibility of the Abdominal Organs and the Influence of the Injections of Cocain upon It, *Med. Rec.*, 70, 1906, 1017ff; Die Sensibilität der Bauchorgane, *Mitteilung. a. d. Grenzgeb. d. Med. u. Chir.*, 19, 1909, 586ff.

tions in which a local anesthetic had been used. On the ground of these papers, Meumann made a final plea[12] for the sensitivity of most of the internal organs; and later Hertz summed up, in a book,[13] the work of the English investigators in evidence of widespread sensibility. In the same year, however, Mitchell[14] published an account of cases, by means of which he endeavored to show that, to a great extent, abdominal pain originates in the parietal peritoneum.

Besides all this work upon the general sensitivity of the viscera, a great deal has been written upon the problem of hunger and appetite. Notable publications are those of Sternberg[15] and Turró.[16] Cannon[17] and Cannon and Washburn[18] have shown the dependence of hunger upon the contractions of the stomach, and Carlson[19] has since confirmed their results. These investigators have also identified hunger with a form of visceral pain.

All the work upon the internal sensibility preceding 1910 has been reviewed by Neumann,[20] who gives a bibliography of sixty-nine titles.

The problem of the sensibility of the inner organs is threefold,—physiological, psychophysical, and psychological. The physiological problem is that of the sensibility of the various organs. In what organs do the different sensations originate? Or, more specifically: where are the nervous terminations, involved in the impulses that condition the sensations, situated? Interest in the quality of sensation is secondary to interest in its conditions. The psychophysical problem is that of the correlation of sensation and stimulus. It is answered by a determination of limens, and of the adequacy of certain stimuli for certain qualities of sensation. It leads further to the question of the localization of the sensations in various parts of the

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[12] Weiteres zur Frage der Sensibilität der inneren Organe, und der Bedeutung der Organempfindungen, *Arch. f. d. ges. Psychol.*, 16, 1909, 228ff.

[13] Hertz, A. F., The Sensibility of the Alimentary Canal, 1911.

[14] Mitchell, J. F., Sensibility of the Peritoneum and Abdominal Viscera, *Jour. Am. Med. Asso.*, 57, 1911, 709ff.

[15] Sternberg, W., Der Hunger, *Zentralbl. f. Physiol.*, 23, 1909, 105ff; Der Appetit in der experimentellen Physiologie und in der klinischen Pathologie, *ibid.*, 23, 1909, 305ff; Physiologische Psychologie des Appetites, *Zeitschr. f. Sinnesphysiol.*, 44, 1910, 254ff; Die Physiologische Grundlage des Hungersgefühls, *ibid.*, 45, 1910, 71ff; Der Appetit in der exakten Medizin, *ibid.*, 45, 1911, 91ff; Das Appetitproblem in der Physiologie und in der Psychologie, *Zeitschr. f. Psychol.*, 59, 1911, 91ff.

[16] Turró, R., Die physiologische Psychologie des Hungers, *Zeitschr. f. Sinnesphysiol.*, 44, 1910, 330ff; 45, 1911, 217ff, 327ff; Psychophysiologie de la faim, *Jour. de psychol.*, 7, 1910, 289ff, 409ff; 8, 1911, 332ff, 417ff.

[17] Cannon, W. B., A Consideration of the Nature of Hunger, *Pop. Sci. Mo.*, 81, 1912, 291ff.

[18] Cannon, W. B., and Washburn, A. L., An Explanation of Hunger, *Am. Jour. Physiol.*, 29, 1912, 441ff.

[19] Carlson, A. J., Contributions to the Physiology of the Stomach, *ibid.*, 31, 1913, 151ff, 175ff, 212ff, 318ff; 32, 1913, 245ff, 369ff; especially, The Relation between the Contractions of the Empty Stomach and the Sensation of Hunger, 31, 1913, 175ff.

[20] Neumann, A., Ueber die Sensibilität der inneren Organe, *Centralbl. f. d. Grenzgeb. d. Med. u. Chir.*, 13, 1910, 401ff, 449ff, 481ff, 529ff, 573ff, 617ff, 656ff, 696ff.

body. Interest is directed equally upon quality of sensation and upon the physical values of the stimulus or the anatomical position of the parts of the body. The psychological problem is that of the quality of the sensations. It requires an exact description of a certain class of experiences as they occur. Interest in the nature of the experience, and especially in its quality, is primary.

In the actual case, no one of these problems is entirely distinct from both the others. It may be said, however, that, so far, the physiological problem has been the most vigorously attacked. Weber, Lennander, Ritter, Kast and Meltzer, all the clinical workers, and all those who experiment upon animals ask first: What organs are sensitive? Meumann and Becher are but very slightly more psychological in their point of view, although they touch at times both upon the psychophysical problem of sensitivity and upon the qualitative nature of sensation. Hertz, Cook, and Schlesinger have much the same outlook. Meumann and Becher both speak of the ability to localize the sensations; they agree that with practice the organic sensations are easily localized, and that with this practice in localization their indefinite quality disappears. They do not, however, present definite data upon the form and amount of errors of localization.

The present study attempts to deal, from the psychophysical and psychological points of view, with the problem of the sensations arising from the stimulation of the alimentary canal. The writer has endeavored, by keeping a careful record of the intensities used, to note the dependence of sensation upon intensity of stimulus. He has attended to the direction, amount, and character of the errors of localization,—recording the localization, whenever it was mentioned, and performing a special experiment for the determination of the amount of reference for one class of stimuli. He has sought to obtain a description of the psychological character of the experiences, by the taking of full introspections upon all occasions. A statement of methods and results follows.

Experimental Work

I. *Procedure and Apparatus*

Observers and Experimenters. The following persons took part in the experiments:

B, the writer of this article, instructor in psychology; C, Miss J. N. Curtis, scholar in psychology; D, Mr. F. L. Dimmick, undergraduate, major subject in psychology; F, Dr. W. S. Foster, instructor in psychology; G, Miss M. E. Goudge, fellow in psychology; Ga, Mr. F. J. Gates, undergraduate, major subject in psychology; R, Mr. G. J. Rich, undergraduate, major subject in psychology.

The principal observer was B. He easily accustomed himself to the swallowing of the stimulus tubes, and his personal interest in

the experiment tended to offset the discomfort. He kept ahead of the other observers; all new series were first tried with him; and very many more were completed by him than by the others. C, D, Ga, R, and occasionally G acted as experimenters for him.

D, F, and G also acted as observers in all the work upon the esophagus and stomach. They completed the principal series with the various sorts of stimuli, although the data obtained from them were less extensive than those obtained from B. D readily learned to swallow the tubes, and in spite of a constitutionally weak stomach proved to be a very satisfactory observer. F also had little difficulty in learning to swallow the tubes, but was unable to retain them for long periods. As he never acquired the ability to talk with the tube in place, the tube had always to be removed before he gave a report. He was especially sensitive to the mechanical stimulation of the stomach and of the upper esophagus, and when the tube was in these positions frequently vomited before the stimulus could be given. G, who had a small pharynx, always swallowed the tube with great difficulty. When it was once in place, however, she found comparatively little difficulty in retaining it or in talking. R, after much patient effort, proved unable to overcome the gagging reflex and to get the tube past the pharynx, and could not be employed.

Stimulus Tubes. The following forms of tube were used for introduction into the esophagus or the rectum. They will be referred to hereinafter by number.

1. For thermal stimulation of the esophagus and for practice. Single tube, heavy wall, red rubber. Lumen, 3.5 mm.; outside diam., 7.0 mm. Used only in preliminary experiments and for practice in swallowing, on account of thinness of wall. A catheter was also used for practice.

2. For thermal and chemical stimulation of esophagus and stomach by injection of water or of chemical solutions. Double-walled[21] tube, made of ⅛ in. and 3/16 in. red rubber tubing. Lumen, 3.0 mm.; outside diam., 9.0 mm.

3. For thermal stimulation of esophagus by means of electric heating coil. Very smooth and stiff stethoscope tubing. Lumen, 5.0 mm.; outside diam., 9.0 mm. About the end of the tube is wrapped a coil of insulated copper wire. A hard rubber core is inserted within the tube at this place in order to render the coil firm. The coil consists of 3.8 meters of No. 30 double cotton-covered wire, resistance 1.5 ohms, and is 11 mm. long by 11 mm. in diam. The leads are of No. 22 double cotton-covered wire, and pass up through the lumen of the tube to heavier wires outside. The coil was soaked in rubber cement. All measurements along the tube are made from the center of the coil.

4. For thermal stimulation of the esophagus and stomach by contact with a metallic coil which conducts a current of water. Apparatus consists of a heavy outer tube of smooth red rubber, containing two small rubber tubes within it. Lumen of outer tube, 6.0 mm.; outside diam., 10.0 mm. Lumen of inner tubes, 3.0 mm.; outside diam., 5.0 mm. The inner tubes are thus forced into elliptical section within the outer tube. At the end of the tubes is a coil of brass

[21] The double-walled tube is necessary to prevent conduction. *Cf.* Becher, *Zeitschrift*, 49, 348; Hertz, *op. cit.*, 5.

tubing, 10 mm. long and 10 mm. in diam. The brass tubing has a lumen of 1.5 mm. and an outside diam. of 2.5 mm. It is coiled in 3¾ turns. The lower end of the coil is brought up through the center, and the two small rubber tubes are tied to the two ends of the coiled brass tube. The connections were soaked in rubber cement and drawn up within the outer tube, so that the coil was flush with the outside of the outer tube.

5. For mechanical stimulation of the esophagus by inflation of bladder.[22] Tubing as in 1. It bears on the end a rubber bladder (condum) about 5 cm. long, which inflates to 5 by 4, 6 by 5 cm., *etc.* The bladder is attached to the tube by rubber cement and by wrapping with heavy thread. At the point where the bladder is wrapped, a short piece of hard rubber tubing is placed inside the soft tube, so that the wrapping can be made firm. The joint is about 1.0 cm. long. It is soaked in rubber cement. All measurements along the tube are made from the middle of the bladder.

6. For mechanical stimulation of the stomach by inflation of bladder. Exactly as 5, except that the bladder is about 15 cm. long. Measurements along the tube are made from the proximal end of the bladder.

7. For bipolar electrical stimulation of esophagus and stomach by electric shock. Stethoscope tubing as in 3. Bears at the end two tin-foil rings, each 12 mm. broad. The lower ring is 10 mm. from the end; there are 8 mm. between the rings. Two lengths of No. 24 double cotton-covered wire are carried through the lumen of the tube, and the bared ends are brought out at the positions of each ring and wrapped about the tube over a hard rubber core within. The strips of foil which constitute the rings are wrapped over the wires and held by rubber cement. (This arrangement was less satisfactory than that used later in 8, because the contacts were slightly rough and scratched the throats of the observers.) Measurements were made from a point midway between the two contacts.

8. For electrical stimulation of various points of the esophagus and stomach, without shift of the position of the tube. Tubing as in 3. It bears six pairs of contacts which are, on the average, 0, 15, 20, 25, 30, and 35 cm. respectively from the lower end of the tube (*i. e.*, if measured to a point midway between each pair.) The contacts consist of brass rings, each of which is 6 mm. wide; inside diameter, 8.5 mm.; outside diam., 9.5 mm. Since the tube is 9 mm. in diameter, the rings indent it slightly and thus afford a fairly smooth surface. The contact at the lower end is a rounded cap, which fits over the end of the tube; it is held in place by a rivet. From each one of the twelve contacts a wire is led through the lumen of the tube. The wires are No. 22, copper, silk and cotton triple-covered. (A heavy insulation is necessary to prevent the induction shocks from jumping.) They are connected at the upper end of the tube to heavier wires leading to mercury cups. At each contact the wire pierces the wall of the tube and is soldered to the contact. Each connection is filed smooth, and the tube is filled at the point with rubber cement in order to prevent short-circuiting of the wires by water or by the acid of the stomach.

9. For thermal stimulation of the rectum by injection of water. Double-walled tube, consisting of a heavy rectal tube through which a lighter tube has been run. Lumen, 3.5 mm.; outside diam., 11.0 mm.

[22] *Cf.* Becher, *Zeitschrift*, 49, 350; Hertz, *op. cit.*, 16.

10. For chemical stimulation of the rectum by injection of liquids. Plain, single tube of same tubing as 3.

11. For mechanical stimulation of rectum by inflation of bladder. Of same tubing as 3. Bears on the end of it a bladder, 7 by 4 cm., attached in the same manner as that of 3.

12. For bipolar electrical stimulation of rectum by induction shock. Same as 7, except that the tin-foil is less smooth and is tied on with thread.

Arrangement of Apparatus. A description of the apparatus employed with the tubes for the control of the various stimuli —thermal, mechanical, electrical, chemical—follows.

For the introduction of hot and cold water into the alimentary tract the heavy-walled tubes 2 and 9 were employed, in order to retard conduction by the walls of the tube and to prevent consequent direct stimulation of throat or anus. Still further to reduce the possibility of conduction through the walls, an apparatus (Fig. 1) was devised by means of which a given amount of water at a given temperature could be forced through the tube so rapidly that there was no time for the tube to cool down or to warm up materially. A 100 cc. flask is placed within a 1,000 cc. beaker, which is filled with water and kept at the temperature desired for the stimulus. The volume of the water is such that the temperature does not change rapidly, and may easily be kept within one degree by the regulation of the burner or by the occasional addition of cold water or ice. A thermometer in the large beaker shows the temperature. The water to be injected is drawn in a pipette from the beaker, measured in a graduate, and poured immediately into the flask through a funnel-tube. The opening of a pinch-cock below the funnel-tube both admits the water and also allows the expulsion of air through the parallel tube. The pinch-cock is closed after the water has been poured in, and the water is allowed to stand for about a minute in order that it may resume the temperature of the bath. It is then forced into the stomach-tube or the rectal-tube by blowing air into the flask by means of a rubber bulb. This bulb is an ordinary syringe bulb, containing valves that prevent the return of the air. With a little practice the experimenter learns the squeeze that is necessary to force a given amount of water into the body with a minimum of accompanying air.

The same apparatus was used, without the temperature bath, for the introduction of chemical solutions and solids in suspension into the alimentary canal.

Mechanical stimulation of the alimentary tract was accomplished by the inflation of a rubber bladder: tubes 5, 6, and 11. The apparatus is shown in Fig. 2. The bladder on the end of the tube is pumped up directly by a syringe, and the pressure is measured by the height of a water column. The tube for the column is 150 cm. high; it was, however, seldom necessary to go above 70 cm. The body of air in the large bottle is intended to act as a cushion, and to prevent the minor fluctuations of pressure that occur with the pumping and with the action of peristalsis upon an inflated bladder. It is necessary to have the bottle of large cross-section, in order that the rise of water in the tube will not appreciably lower the level in the bottle and thus change the zero-point. The level of the water in the system is controlled by filling from the funnel-tube, which is ordinarily shut off by a pinch-cock. The observer lies upon a couch at such a height

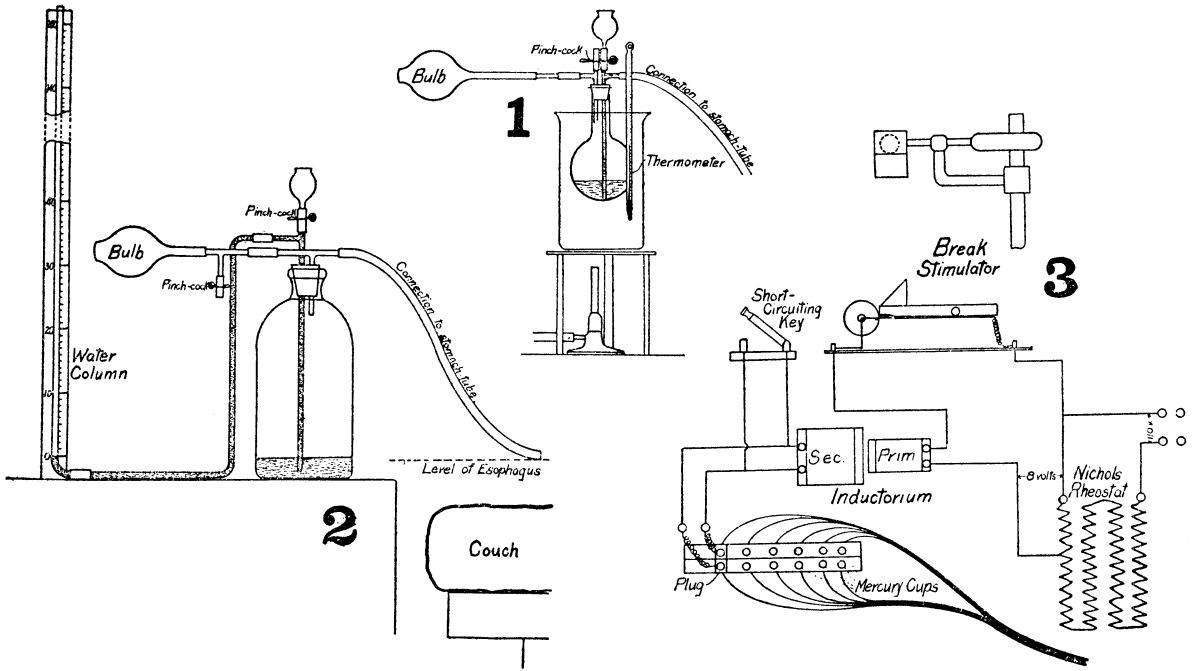


FIG. 1.—Apparatus for the introduction of a liquid at a given temperature under air pressure into the alimentary tract.

FIG. 2.—Apparatus for the inflation of a rubber bladder with air and the measurement of the pressure.

FIG. 3.—Apparatus for the bipolar electrical stimulation of the esophagus by break-shocks at 5 different points.

that the esophagus is approximately at the same level as the water in the bottle. A pinch-cock, connected with the stomach tube provides a means of release for the air after inflation.

In subsequent experiments, in which it was desired to control the rate of inflation, a bicycle pump was substituted for the rubber bulb. The pump was placed horizontally and in a convenient position and the piston rod put through a hole in a fixed metal plate. Two metal stops on the rod, one on each side of the plate, limited the length of stroke to 4 cm. The pump was worked by hand. As each stop came against the plate a metallic click resulted. The rate was controlled by the experimenter, who took care to make these clicks coincide with the clicks of a metronome. In a trial series it was found that the pressures obtained by an equal number of strokes were practically identical for rates varying from 15 to 75 per min.

For the esophagus and rectum it is probably fair to assume that the pressure measured by the water column is practically all exerted upon the tissues; that is to say, that the pressure is not reduced by the force necessary to expand the bladder alone. This assumption is approximately correct, because the bladder is confined within a tube and not allowed to expand in the normal spherical form. In the inflated bladder the only expansion is toward the end, and the internal pressure,—everywhere equal, and normal to the surface, by the law of hydrostatics,—must be transmitted almost entirely by the unexpanded side-walls of the rubber bag. Only to the extent that the esophagus or rectum stretches beyond the unexpanded diameter of the bladder is the measurement inexact. The error is probably greater in the stomach, where the bag takes more nearly the form that it would assume if it were inflated without constraint.

Fig. 3 shows the final form of the apparatus for electrical stimulation, as it was used with tube 8. The six pairs of contacts on the tube were connected with six pairs of mercury cups. The secondary of the induction coil was connected with a plug, made of a block of hard rubber bearing two pins which could be thrust simultaneously into a pair of mercury cups. In this manner the coil could be connected very readily to any pair of contacts on the tube. The induction coil is a 'standard'[23] coil, with a primary 13 cm. long and 10,000 turns in the secondary, manufactured by Zimmermann.[24] A removable core was kept within the primary throughout the trials. The scale for the secondary runs from zero to 20 cm. The coil was, however, calibrated in Kronecker units, and all values of inductive strength will be given in these units.[25]. Only break-shocks were used; the make was eliminated by a short-circuiting key, connected with the secondary. In the early experiments a telegraph key was used to break the circuit. This procedure, however, proved so inconstant that a Titchener sound-stimulator[26] was substituted. In this instrument a

[23] The dimensions of a standard induction coil are discussed by Martin, E. G., *The Measurement of Induction Shocks,* 1912, 88f.

[24] No. 1901 of Catalogue 20, 1908.

[25] For the method of calibration, see Kronecker, H., Ueber die Ermüdung und Erholung der Muskeln, *Arbeiten aus der physiol. Anstalt z. Leipzig*, 1871, 186; Martin, *op. cit.,* 16ff. The writer is indebted to the Dept. of Physiology of the Cornell Medical College for the use of their Kronecker coil and Martin key.

[26] For full description and figure of this instrument see Titchener, E. B., Experimental Psychology, vol. ii, pt. i, 1905, 153ff.

marble is dropped from a constant height (in this experiment, 22 cm.) upon a table, which rocks slightly about a pivot, breaking a circuit between a plate on the lower surface of the table and a pin set in the circumference of a wheel that is rotated by friction with the table. The break is very quick. Constancy is secured by the fact that contact can be set in only one way and that, after the release of the marble, the operation is entirely mechanical. The current employed was taken from a Nichols rheostat connected with a 110-volt direct current line. The open-circuit voltage of the primary circuit was 8 volts.

The same apparatus was used with tubes 7 and 12, with the omission of the mercury cups. The single contacts were connected directly with a pair of binding posts in circuit with the secondary coil.

The heating coil of tube 3 was connected directly with the 8-volt connections from the Nichols frame. A variable resistance was placed in the circuit with the secondary coil, but it was found unnecessary to use it. The intensity of stimulation depended in any case upon the length of time during which the current was allowed to flow; and the increase was found to be not too great with 8 volts, whereas with less than 8 volts the initial warming-up to the limen took too long.

It should perhaps be mentioned that an unsuccessful attempt was made to use unipolar stimulation. A sponge electrode of about 100 sq. cm. was attached to the arm, and the esophagus and stomach were stimulated. The sensations in the arm were noticeable long before any sensation from the alimentary canal could be observed. The intensity might have been increased to an amount sufficient to bring out the internal sensations; but the movement and the extreme discomfort induced in the arm would have proved too great a distraction, even if it would not have raised a question regarding the exact seat of the stimulation. It would have been possible to use a larger electrode; but the desire to confine the current as far as possible to the area under investigation forbade this attempt.[27]

General Procedure. Before the experimental work began, the observers had to learn to swallow the stomach tubes. They first tried the catheter and tube 1. They were instructed to swallow on the tube, to take it as one might a bolus. To aid in the swallowing, water was sometimes allowed to trickle slowly through the tube. As we have seen, the observers differed greatly. F from the first preferred a tube large enough to be so stiff that he could thrust it down rapidly. G, on the other hand, gulped the tube down very slowly inch by inch.

When the observers were first required to talk with the tube in place, they hesitated and spoke very little. Within an hour, however, they found themselves able to talk continu-

[27] Becher, however, did use unipolar stimulation with the whole arm immersed in water. He thought that, since he had proved the sensibility of the esophagus, there was but little doubt that the sensations originated there. *Zeitschrift,* 49, 352.

ously, with occasional pauses when the tube tickled the throat and started the gagging reflex. F was an exception to this rule, for he never became able to talk without vomiting, although he tried again and again. Work was thus slower with F than with the others, for it was necessary to remove the tube after each observation. The swallowing is the most uncomfortable (and sometimes painful) part of the operation. Hence in the case of F the series were not only delayed in the actual time consumed, but were also limited in the number of observations that could be taken in a single hour. For this reason fewer observations were in general taken with F than with the other observers.

Toward the end of the experiment, D and G could usually retain the tubes without serious discomfort. B had become so practised by continued work that it was not a great hardship for him to allow experimentation upon the esophagus for four hours in a single day, or to retain a tube continuously for two hours. He sometimes preferred keeping the tube in place, when going upon an errand in the laboratory, to the unpleasantness of having to swallow it again. Toward the end of the experiment he observed five hours a day for a week on the esophageal and rectal work combined. This experience was, it is true, somewhat upsetting; the explanation may lie, however, in the fact many of the stimuli were chemical.

All the experiments were performed with the observer lying supine upon a couch, which was adjusted to place him at the level of the apparatus. The stimulus tube was supported from the observer's mouth by a ring attached to a cord which ran over a pulley to a counterweight.

Localization. The position of the stimulus in the esophagus or stomach is recorded, throughout these experiments, as the number of centimeters from the teeth downward. The observer was instructed to keep the tube lying flat in the mouth, and not bunched up in the throat. In such a system, 15 cm. lies approximately at the junction of pharynx and esophagus; 20 cm., in the upper portion of the esophagus. For F, who is very tall (6 ft. 2 in.), this point must have been quite close to the pharynx. The gastric end of the esophagus lay between 40 and 45,—in B at about 45. This point was determined by the ease with which a bladder could be expanded within the tract, and by a radiograph (not reproduced in this paper), taken with the tube in, in which a shadow of the stomach, distended by gas, appeared. With the limits of the esophagus

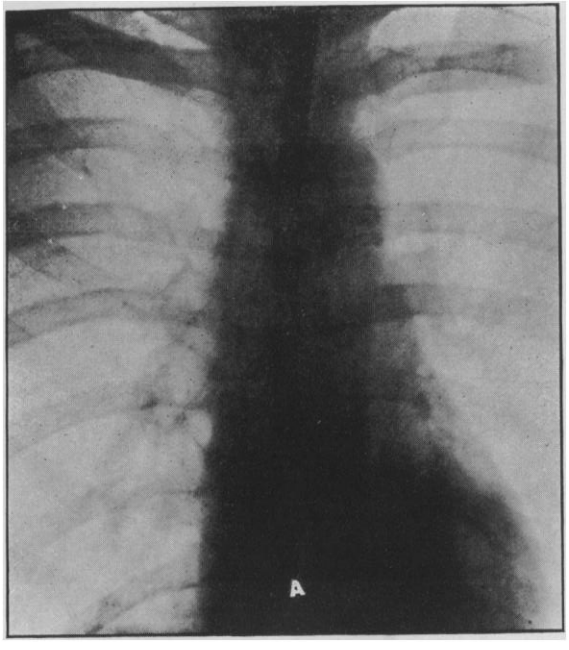


PLATE I

Radiograph of Observer B with esophageal tube in place. A = end of 40 cm. tube.

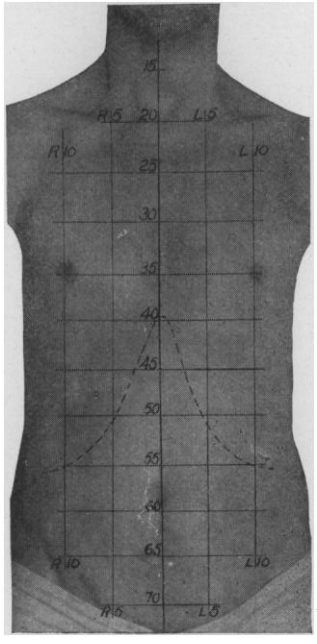


PLATE II

Coordinates for localization in relation to superficial anatomy. Observer B. Longitudinal scale corresponds to distance from the teeth of underlying points in the esophagus.

thus fairly defined, five points,—40, 35, 30, 25, and 20 centimeters respectively from the teeth,—were selected for investigation. They will be referred to by these numbers. The upper end of the esophagus is 20; the lower end, 40. There was no means of controlling the position of the end of the tube after it had entered the stomach. Ordinarily the setting 50 was taken for an observation upon the stomach. Occasionally 45, 55, and 60 were used.

The observers were required in all the trials to localize the sensations reported. In the cases of D and G the localization was made by reference to such definite anatomical parts as the larynx, clavicle, nipples, sternum, ribs, and umbilicus; or by indication upon a large outline diagram similar in form to the small ones shown in Figg. 4 *et seq.* The localization was recorded both verbally, and diagrammatically upon a smaller outline diagram which was placed on the record sheets by means of a rubber stamp. These general means of localization were supplemented, in the cases of B and F, by laying off the surface of the body in five-centimeter squares, as is shown in Plate II. Plate II is a photograph of B, and shows the anatomical relations. The longitudinal scale indicates the distance in cm. that a point at that level in the esophagus is from the teeth. The relation of the position of the tube, as measured from the teeth, to the surface of the body was determined for B by means of the radiograph of Plate I.[28] The transverse scale reads to left and right of the median axis. Thus the right nipple would be designated as 35R10, *i. e.,* 35 cm. down and 10 cm. to the right. The lines were sometimes marked off on the skin in grease pencil, the sternum, nipples and umbilicus being taken as basal points. More often however, the observer wore a 'localization map.' This 'map' consisted of a very tight-fitting undershirt, which was made to conform even more exactly to the body by elastic straps at the back and from front to back between the legs. The coördinates for localization were marked upon the shirt. Its adjustment could always be checked by reference to anatomical points.

[28] The clavicle and ribs are sufficiently clear in the radiograph and could be located with sufficient distinctness in the subject to establish the local relations. Between the measurements made upon the radiograph and those made upon the subject there was an average difference of 3.8%,—a difference which was neglected.

The following anatomical relations for B in terms of the scale show the significance of the numbers:

Top of larynx	12.5
Bottom of larynx	17.5
Level of clavicle	20.0
Nipples	35R10, 35L10
Lower level of sternum	40.0
Lower level of ribs	54.0
Umbilicus	58.0
Lower level of *symphysis pubis*	74.0
Base of penis	76.0

II. The Esophagus

1. *Thermal Stimulation*

Sensibility. The principal source of data upon the thermal sensibility of the esophagus is furnished by the series taken with tube 3. In these series, 35 cc. of water at different temperatures were injected under pressure into the esophagus. The method has been described above. Five positions of the tube (40, 35, 30, 25, and 20 cm.) were used with B and D, and three (40, 30, and 20 cm.) with F and G. In all these series the first observation was taken at the lowest position, and the tube was then pulled up; it was much more difficult for the observer, lying down, to have the tube pushed in than to have it pulled out. Temperatures of 0° C and 50° C were used with all the observers. With B many other temperatures were also used. In addition to these series, in which the position of the tube was varied while the temperature remained constant, a single series, in which the tube was at 30 cm. while the temperature was increased by small steps over the middle range of the temperature scale, was carried out upon each observer. The results (so far as a full introspective report, sometimes of as many as 200 words, can be reduced on its qualitative side to one or two words) are shown in Tables I, II, III, and IV for the four observers respectively. The observations recorded in these tables were taken in serial order from left to right for a single temperature, with the exception of those recorded in the column headed 30(II). This column gives the results of the series in which the temperature was increased with the tube at 30 cm. The plus sign (+) represents the successive appearance of the factors indicated.

The position of the end of the tube does not, of course, indicate the exact point of stimulation, since the water, after injection into the esophagus, continues downward. For this reason, any reports of temperature that occurred more than

TABLE I

Sensibility of esophagus to temperature. Observer B. Stimulus 25 cc. of water at given temperature introduced through tube 2. Position of end of tube recorded in cm. from teeth. Successive appearance of two factors is indicated by +.

Temp. of Water, °C.	Position of end of tube					
	40	35	30	30 (II)	25	20
0	cold	cold	cold		cold	cold
10	cold	cold	cold		cold	cold
20	cold		cold			cold
30	cold		cold			cold
35	cold		cold	cold		cold
37				cold		
38	cool		cool			cool
39				cool		
40	cool	cool	cool		cool	cool
	+warm	+warm	+warm		+warm	+warm
41				cool		
				+warm		
43				cool		
				+warm		
45				cool		
				+warm		
47				cool		
				+warm		
49				cold		
				+warm		
50	cold	cold	cold		cold	cold
	+heat	+warm	+warm		+warm	+warm
60	heat	cold	cold		cold	cold
		+heat	+heat		+heat	+heat
70	cold		cold			cold
	+heat		+heat			+heat
						+pain
80			heat			
			+pain			

a few seconds after the beginning of the stimulation have been excluded from the tables. The water must have spread out, and have approached body-temperature, very rapidly after leaving the tube. The most intense sensation would thus probably occur somewhere in the neighborhood of the end of the tube. The generalization that the sensations reported depend upon the stimulation of the region of the esophagus at the end of the tube cannot be made with any great rigor. It is, however, supported to some extent by certain facts. (1) The esophagus can be shown to be sensitive to tempera-

TABLE II

Sensibility of esophagus to temperature. Observer D. Same as Table I.

Temp. of Water, °C.	Position of end of tube					
	40	35	30	30 (II)	25	20
0	cold	cold	cold		cold	cold
20				cold		
31				cool		
35				cool		
39				cool?		
43				warm		
47				warm		
50	warm	cool +warm	cool +warm		cool +warm	cool +warm
51				warm		
55				warm		
59				warm		
63				warm		
67				heat		
71				heat		

TABLE III

Sensibility of esophagus to temperature. Observer F. Same as Table I.

Temp. of Water, °C.	Position of end of tube			
	40	30	30 (II)	20
0	cold	cold	cold	cold
31			cold	
35			cold?	
39			nothing	
43			nothing	
47			warm	
50	warm	warm		warm
60	warm	warm		warm

ture, throughout its length, by other means (tubes 3 and 4) which will be described later, and has been shown to be thus sensitive by other investigators. The results obtained by the present method agree substantially with those obtained by the other methods. (2) The esophagus appears to be more sensitive toward the upper end than the lower. This difference

TABLE IV

Sensibility of esophagus to temperature. Observer G. Same as Table I.

Temp. of Water, °C.	Position of end of tube			
	40	30	30 (II)	20
0	cold	cold		cold
23			cold	
27			cold	
31			cold	
35			cold	
39			cool	
43			cool	
47			cool +warm	
50	nothing	warm		warm
51			cool +warm	

in sensitivity must be real, for, if the sensation were due to stimulation by water at a lower level, the upper esophagus would appear less sensitive than the lower, since, with the tube in the higher position, the water would have farther to go and would hence have assumed a more nearly neutral temperature before it had reached a sensitive region.

The following points may be noted in connection with the tables.

The esophagus appears to be sensitive throughout its length to cold at 0° C and to warmth at 50° C, though in a single instance G had no temperature sensation at 50°. Our results here are in perfect accord with those of Becher[29] and of Hertz, Cook and Schlesinger.[30]

A noteworthy fact appears in the report of B (Table I). Cool or cold sensations are reported not only for the stimuli below body-temperature, but also for all but two of the stimuli above body-temperature. In the fourteen reports of warm, every warmth is preceded by coolness or cold; in the ten reports of heat, cold precedes in every case but two. D and G occasionally, but by no means universally, find cool sensations preceding the warm. With D the cool sensations occur four times out of thirteen; with G, twice out of four. F, at the other extreme from B, never gets coolness before

[29] *Zeitschrift*, 49, 349f.

[30] *Op. cit.*, 483; Hertz, *op. cit.*, 6.

warmth. There can be no doubt about these cold sensations; they are often more clear-cut and definite than the warmth which they precede. We shall return to their consideration presently.

From inspection of the Tables it is possible to write the approximate liminal values for cold, warmth, heat, and painful heat, which are set up at a point in the middle of the esophagus:

	B	D	F	G
Cold[31]	37	35	35	35
Warmth	40	43	47	47
Heat	60	67	..	..
Painful heat	80	..	..	..

At the lower end of the esophagus in observer B the limen for cold is higher, and for heat lower, than is the case in the middle of the esophagus.

In order to demonstrate more conclusively that the whole esophagus is sensitive to temperature, tubes 3 and 4 were used with observer B. The heating coil of tube 3 was allowed to become hot at the five positions usually selected in the esophogus. In all cases there appeared a sensation of warmth, followed by heat. The heat developed later into pain except at the extreme lower end of the esophagus (40 cm.). Here, too, it might have passed over into pain had the circuit been kept closed for a longer period; B feared, however, to allow the current to pass for more than fifteen seconds under the poor conditions of radiation that probably exist in the esophagus, since the coil would have become very hot and might have injured the tissue. The use of the coil demonstrates the sensibility of the esophagus easily and unequivocally. It is not adapted to quantitative determinations, as it cannot be calibrated without reference to the conditions of conduction and convection that obtain in any particular case; there is theoretically no limit to the temperature that a coil, to which electrical energy is constantly being supplied, may reach, except as a limit is established by the rate of energy-conduction away from the coil under any given set of conditions.

More satisfactory results (see Table V) were obtained with observer B from tube 4. In these trials a current of water (50 cc. altogether) was forced by means of the apparatus shown in Fig. 1 through the brass coil at the end of the stimulus tube. The esophagus proved everywhere sensitive to cold, warmth, and painful heat, with the single exception that pain only was felt for the extreme cold at the upper end of the esophagus.

This stimulus tube has the advantage over that used for the greater number of our experiments that it confines the stimulation to a small area until such time as conduction takes place through the heavy walls of the tube. It has, however, the disadvantage of affording great discomfort to the observers. In fact, after an attempt had been

[31] The figures for 'cold' are temperatures at which a definite, intense cold sensation is felt. 'Coolness' is seen to be reported for higher temperatures.

TABLE V

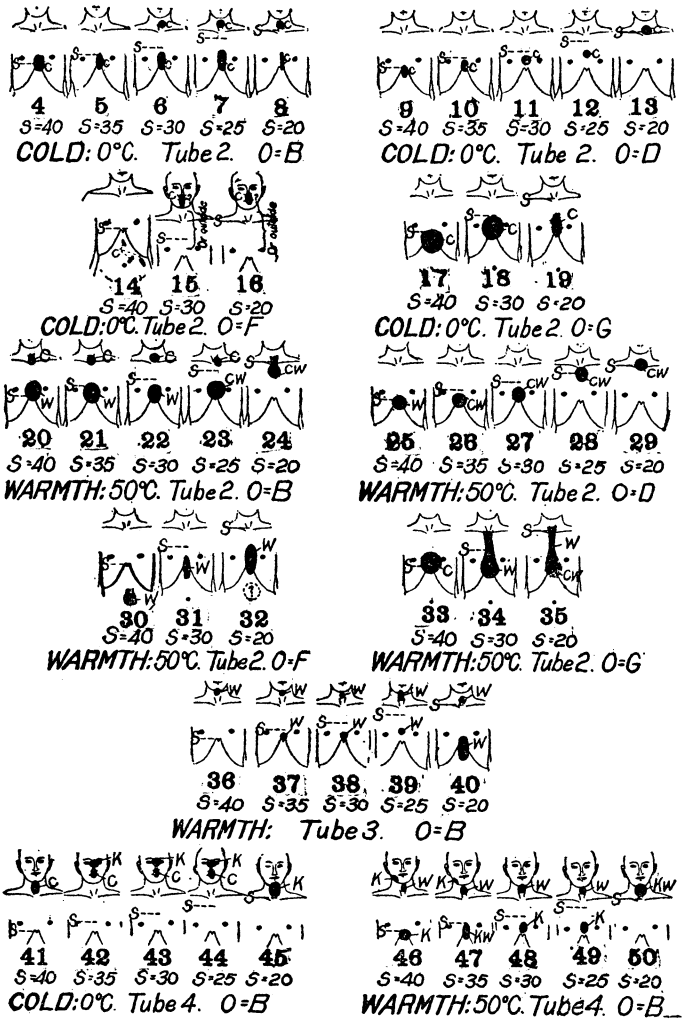
Sensibility of esophagus to temperature. Observer B. Stimulus: current of water at a given temperature passed through the brass coil of tube 4. 50 cc. of water are forced through under pressure, in each observation.

Temp. of Water, °C.	Position of stimulus coil				
	40	35	30	25	20
0	cold	cold	cold	cold	cold
50	warm	warm	warm	warm	warm
60	heat +pain	warm +pain	heat +pain	heat +pain	heat +pain

made to use it with F and D, the resulting soreness of the esophagus persisted for so long a time that it was considered inadvisable either to repeat the attempt on these observers or to try to use the tube with G, who has a small pharynx. The experimenter tried to construct an apparatus which should use as stimulus a loop of light rubber tubing, the ends of which were brought up through the heavy outside tube. He was unable to construct a loop which would not kink, so as to cut off the flow almost completely, even when the water was under considerable pressure. When heavier rubber was used for the inner tube, the loop changed in temperature almost as slowly as the outside tube so that the arrangement seemed scarcely preferable to tube 2. The substitution of a thin rubber sack for the loop also proved unsatisfactory, because the sack when full of water initiated peristalsis and gave rise to distracting pressure sensations.

It is tempting to call the cool and cold sensations dependent upon stimuli above body-temperature 'paradoxical.' We have seen (p. 17), however, that for observer B all stimuli from 0° C to 70° C give either coolness or cold, that there is no *Nullpunktstemperatur*. The same state of affairs occurs when the end of the tube is held in the hand; coolness precedes warmth, for the mass of the tube itself is such that the first volume of water is always cooled down to a point sufficiently below body-temperature to give rise to a sensation of coolness in the normal way. The results for tube 2 thus come into accord with those for tubes 3 and 4, with which no pure warmth sensations were obtained. The difference between observer B, who always gets coolness with warm water, and F, who never does so, may be entirely one of sensitivity. D and G are, perhaps, intermediate.

Is there then no paradoxical cold? The appearance of heat for stimuli more intense than those which give warm and with all three tubes would, on the theory that heat implies cold (von Frey), indicate a paradoxical cold. It is noteworthy that with B (Table I) the initial sensation for the higher temperatures is cold, that is to say, coolness generally precedes warmth and cold heat. It may be that the cold organs respond more rapidly than do the warm organs, as is the case when one thrusts one's hands into hot water, and that this cold is a true paradoxical cold. That it would not be felt with tubes 3 and 4 is natural enough, since these tubes present a stimulus which becomes warm very gradually.



FIGG. 4-50.—LOCALIZATION OF TEMPERATURE IN THE ESOPHAGUS
O = Observer; S = level of stimulus (cm. from teeth).
c = cold; k = pain; w = warmth.

Localization. The localization of the sensation of temperature for typical cases is charted in Figg. 4 to 50.

Localization of cold is shown for four observers in Figg. 4 to 19. Individual differences are apparent. B, for example,

localizes cold both in the throat and in the region of the sternum. G finds cold in the same places as the lower cold of B, but does not refer it to the throat. D tends to localize the stimuli near the sternum, except those at the upper end of the esophagus. F finds localization very difficult for the higher positions of the stimulus; he thinks that the cold may lie in the head or lower down, but he cannot make sure. " My first tendency was to connect the cold with the tactual feeling in the upper part of my throat. This did not seem right. Then I felt the cold sensations outside my body in front of me. They seem to move up and down." With tube 4 at 0° C, B refers cold universally to the throat. He does not find any sensation of temperature in the region of the stomach.

In general it may be said that the sensations, following cold stimulation are referred either toward the region of the stomach or toward the throat; that is to say, they are hardly ever localized in the upper portion of the chest.

The localization of warmth by B, D, and G is similar to that of cold. B always experiences a cold sensation preceding the warmth; the cold is felt in the neck, and the warmth at the sternum. G feels cold at the level of the sternum, but warmth frequently extends up beyond it. D localizes the preliminary cold and warmth in the same place. His localization corresponds more nearly with the position of the stimulus than that of the other observers. F refers the warmth to the abdomen or sternum, never to a higher position. He does not get sensations of cold from warm stimuli.

With the electric heating coil (tube 3), and with the brass coil for water (tube 4), B localizes the sensations in very much the same places as with the single tube (2); but in neither case does he feel cold. With the electric heating coil, the throat sensations and the sensations lower down were those of warmth. With the water coil, the throat sensations were warm, while the sensations lower down consisted of a dull pain or ache.

In general we may say that the warmth sensations tend to be localized in the region of the sternum or below, when warm water is introduced through a straight tube, although numerous exceptions occur with other methods of procedure (Figg. 36-40, 46-50). The cold aroused by warm stimuli is referred to the neck by B, to the region of the sternum by G, to the same place as the warmth by D, and is not reported by F.

Quality of Sensation. The reports of the observers indicate the character of the complexes aroused by thermal stimulation. The following excerpts apply for 0° C and tube 2.

B, 40 cm. "Besides usual bubbly sensations, cold developed quite definitely in long strip extending about 2 inches on either side of sternum. It lasted with some slight fluctuation to the end, by which I mean, the place where all relevant sensations stop. Considerably above this a very keen fresh cold came in,—like eating peppermint. I intended at first to localize this in my throat, but when I attended to throat it seemed as if the cold must be farther down. Then I tried to locate it with my finger, but could not decide whether it was in my throat or opposite my clavicle or considerably lower down. The thing seemed peculiarly evanescent."

B, 35 cm. "Lots of cold like that described last time. Then very intense cold extending all the way down the throat to my sternum, but although it seems continuous it seems to skip my neck. I visualize these sensations as continuous when I think of them as inside, but there seem to be about four inches of neck missing when I think of them with reference to the surface of the body."

D, 35 cm. "Cold sensations very noticeable; seem to be combined with a lump of pressure."

D, 20 cm. "Extremely cold, and sort of refreshing; quite high up in the throat."

F, 40 cm. "Moderately intense cold, which seems to be in front of bubbly sensations at body wall. Nothing is in front of my body. There was another cold inside, and a third higher up."

F, 30 cm. "My first tendency with the cold was to connect it with the tactual feeling of the tube in the upper part of my throat where I feel the tube most. This did not seem right. Then I felt the cold sensations outside my body in front of me. They seem to move up and down; and then, because I knew the length of the tube in the esophagus was not great, I tried to localize them down below the sternum; but this did not seem right either. The cold is farther in front, perhaps even outside the body."

G, 30 cm. "Auditory and pressure sensations in stomach—bubbly sensations. Cold came blended with these sensations, but did not stand out clearly at first. Afterwards, however, it became clearer. It lasts a long time; I still feel a tiny bit of cold in my stomach."

G, 20 cm. "Much the same as before. Cold not different on edges but different in midline. At first it was mixed in with stomach sensations. It stood out quite clearly after the beginning. At the end there was just a pattern of the cold sensations left."

With the water coil at 0° C and tube 4, B reports as follows:

B, 40 cm. "Very intense cold in throat and at top of pharynx. It develops and gets very intense rapidly. Coldness on the lips and tongue (probably from the conduction through the walls of the tube) come very much later. No sensations below clavicle."

B, 30 cm. "Intense cold in tiny little spots way high up above the base of the uvula."

B, 25 cm. "Cold lasts right through and becomes larger and 'achy' toward the end. I can feel this dull ache up in the region above the uvula at the same time that I feel coolness in the mouth from the tube. By a shift of attention I can also localize the cold back of the bridge of the nose, which is where I localize the intense pains which come from eating ice-cream too fast."

There is on the basis of the reports no reason to suppose that cold from the esophagus is qualitatively different from cutaneous cold. The sensations are generally referred to a large area, and the indefiniteness often ascribed to them seems to be principally a matter of difficulty of localization of this area. Either the region is not exactly placed, or its boundaries are poorly defined, or it is localized differently by different methods of judgment. B, for example, reports an indefinite sensation which he tended to localize in one place with visual imagery and in another by arm-kinesthesis. The indefiniteness is probably also a matter of intensity. Weak sensations covering a large area are apt to be called indefinite. Besides this indefiniteness, the dull pains that frequently accompany the esophageal colds are apt to give a specific qualitative coloring to the experience. Careful analysis, however, seems to separate the 'achy' cold into two components, the one of which is not unlike the cold of the skin.

The character of the sensation aroused by warm stimuli appears in the following quotations.

B, 40 cm. "Very different and quite intense cold sensations well up in region of clavicle. This cold is a little spot about two inches long and one inch wide, although the boundaries were not definitely defined. It reached maximum intensity rather quickly, though not suddenly, and died down considerably more slowly. Then a short period with no cold in it, but possibly a very weak warmth. Later the warm sensation became definite, reaching a maximum much more slowly than did the cold. At maximum intensity it seemed very slightly hot,—at least there was some qualitative change in the direction of getting more clear-cut and compact."

B, 30 cm. "Cold in throat early as before; then a less definitely localized cold lower down; followed by warmth. The warmth is quite diffuse, and not like cutaneous warmth, but as if something unpleasant were set on a background of cutaneous warmth. It is not just like heat because this something is not so sharp, definite, and clear-cut."

B, 20 cm. "This time the cold went over into warmth by way of heat. Instead of there being a low place in the temporal course between the cold and the warmth, there was a high place. I can distinguish the cold in this heat. Heat becomes less intense and then turns to intense warmth which dies out fairly rapidly."

D did not discriminate qualitatively between warmth from the skin and warmth from the esophagus.

F, 40 cm. F first describes "bubbly sensations" which are due to the injection of water through the tube and which were localized in the center of the body about the umbilicus. He finds warmth in front of the sensations and covering them.

F, 30 cm. F finds warmth as part of a complex of pressure and warmth. "The warmth is well forward in my body, very hard to localize. If you are going to get it as exactly as possible, you would say it was less than an inch below the surface of the body. No particular thickness to the warmth, which is a thin sheet."

G, 30 cm. "Weak, bubbly, followed by warm pattern. Localized warmest part just below sternum extending up into sternum. Strange to say there was also warmth from clavicle down to stomach. Wondered if I got it way up in top of throat, but decided I did not."

G, 20 cm. "Bubbly pattern, followed by weak cold in stomach; followed by and overlaid by warmth—warmer than before localized—strongest in clavicle region. Also some warmth below though this was not intense. Should say attention was on cool at first; then on definite warmth above; and then on indefinite warmth below."

It appears, then, that if any difference in quality exists between warmth from the esophagus and warmth from the skin, it is neither great nor obvious. The lower warmths, like the colds in the same region, are frequently described as indefinite or vague, but no observer calls this a qualitative difference, with the single exception (noted above) that B suggests there may be some "qualitative change in the direction of getting more clear-cut and compact."

We cannot enter here into a discussion of the possibility of a description of qualities in terms that ordinarily have an extensive connotation (*e. g.*, 'granular pressure'). As regards the validity of the qualitative distinction hinted at by B, it may be remarked that, although B found the warmth in the stomach vague and indefinite, he was able under special conditions to equate it to warmth of the skin (see p. 44). Further introspections indicate that the warmth at the lower end of the esophagus was more like heat. Of the exact analysis of heat, B has never been able to make up his mind. In it, warmth is usually clear for him. Cold is sometimes, but rarely, discernible; although cold differs from warmth in much the same way that heat does, *i. e.*, in definiteness and clear-cutness. His introspection, however, does not lead him to believe that the introduction of cold alone will change warmth to heat. When warmth becomes heat, it seems as if a 'stinging' sensation, which belongs to the family of pains, were added to it; and the existence of such a sensation is supported by the fact that it seems to occur in isolation when the glans penis is stimulated by warmth. It is possible, then, that for B stimulation of the lower esophagus by warmth tends to bring out, along with warm sensations, some sort of pain complex, which is perhaps not unlike a factor in the typical pattern for heat. This painful addition might account for the 'unpleasant warmth' described by Head as the characteristic internal warmth. In any event there seems to be no question but that the warmth from the upper esophagus is like that of the skin. All observers find them similar in character. This upper warmth passes often into a normal heat in the usual way.

Thermal Pain. Both cold and warm stimuli in the esophagus sometimes give rise to pain. The pain is frequently localized with the sensation of temperature. There are, however, many cases in which pain is referred to the head (see Figg. 42-47). The localization of these pains in the head is very indefinite. B nearly always finds them deep in. They

seem to alter their position for him, however, with alteration of direction of attention; *e. g.*, when visualized from the front they appear to be behind the bridge of the nose, when visualized from the mouth they appear to be up above the uvula. Sometimes, especially with warmth and nausea, an indefinite pain occurs in the jaw. It is hardly possible to place this pain more specifically than to tell which side it affects. The thermal pains are of the indefinite ache-like character of many of the organic pains. In one form they are familiar to most people, as the pains experienced in the head when eating ice-cream too rapidly.

The prevalence of 'ice-cream pains' was determined by questioning a class of forty-five students. Thirty-eight were accustomed to feel the pains when they ate ice-cream too quickly. The seven who never felt the pains did not characterize themselves as 'rapid eaters.' Those who were accustomed to them localized them variously as follows: head (2); front of head (3); head above nose, forehead over eyes, between eyes, bridge of nose, above nose, base of nose (23); temples (3); roof of mouth, soft palate (4); jaws (1); throat (1); below throat (1); intestine (1).

These pains have been explained as resulting from the stimulation of the esophageal and gastric branches of the vagus. The former ends in the esophageal plexus and lies close to the esophagus especially at the lower half. This distribution accords with the fact that the pains occur more readily upon the stimulation of the lower end than they do when the middle region of the esophagus is excited. The pharyngeal branch of the vagus may be responsible for the pains originating in the throat. The reference of the pains to the head may in some way be due to the fact that two branches of the vagus (meningeal and auricular) are distributed in this region.[32]

2. *Mechanical Stimulation*

Sensibility. The sensibility of the esophagus to mechanical stimulation was studied by inflation of the rubber bladder of tube 5. The apparatus has been described (see Fig. 2).

In Table VI are shown, in terms of cm. of water, the intensities of pressure required to produce in the first place a just noticeable sensation of pressure, and in the second place a just noticeable sensation of pain. The two values of pressure shown for B represent two separate series. The results are not exact to less than 5 cm.; because the column of water, owing to the fluctuations caused by peristalsis and the tendency of most observers to squeeze the tube involuntarily between the lips, did not remain constant.

The Table shows, not only that the esophagus is sensitive

[32] Indigestion is said to be sometimes accompanied by a ringing in the ears.

to pressure and to the pain of distension, but also that its sensitivity increases toward the upper end.[33]

TABLE VI

Sensibility of the esophagus to pressure and to pain. Figures show the approximate intensity of pressure in cm. of water necessary to arouse a just noticeable sensation. Tube 5.

Position of Stimulus, cm.	Pressure				Pain			
	Observers				Observers			
	B	D	F	G	B	D	F	G
40	31, 21	30	30	35	40	50	40	40
35	15, 15	30		25	45	40		37
30	20, 26	25	30	25	40	45	40	32
25	12, 21	20	25	20	37	40	40	40
20	13, 25	25		5	35	40		20

The statement is ordinarily made that the limens for the sensations dependent upon the distension of the alimentary tract vary with the rate of distension. To test this assertion the rate of inflation was controlled by the use of the pump (p. 10). Five trials were taken at 30 cm. with each of five rates ranging from 15 to 180 half-strokes per min. The average liminal intensities for pressure expressed in cm. of water are as follows:

Rate (half-strokes per min.)	15	30	60	120	180
Average of 5 trials.....	33.3	28.3	23.3	21.9	19.5
Mean variation	4.1	4.8	7.8	4.1	1.0

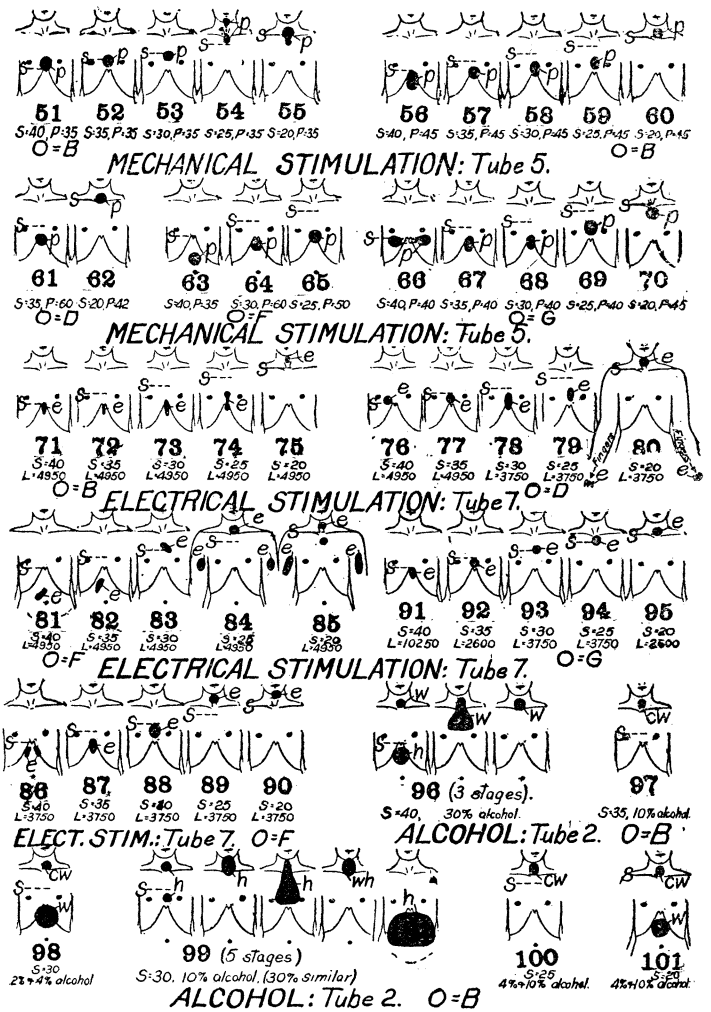
Although the M. V.'s are large, there can be no doubt but that the limen for pressure is decreased with an increase in the rate of distension.

The liminal values for pain from the inflation of the esophagus at 30 cm. are:

Rate (half-strokes per min.).....	30	60	120	180
Average of 5 trials.....	42.3	44.8	43.5	41.8
Mean variation	4.3	3.8	6.0	4.7

There is no evidence that the limen for pain is dependent upon the rate of inflation. This conclusion must not be drawn too

[33] Hertz (*op. cit.*, 16) finds a limen equivalent to 60-70 cm. of water for the sensations of 'fulness.' He denies tactile sensibility (p. 3). Becher (*Zeitschrift*, 49, 351) reports that the esophagus of his observer was sensitive to both pressure and contact.



FIGG. 51-101.—LOCALIZATION OF MECHANICAL, ELECTRICAL, AND CHEMICAL STIMULI IN THE ESOPHAGUS

O = Observer; L = intensity of electric shock (Kronecker units); P = maximum intensity of pressure (cm. of water); S = level of stimulus (cm. from teeth).

c = cold; e = electric shock; h = heat; p = pressure; w = warmth.

rigorously, however. At these high pressures peristalsis is induced so vigorously[34] that the water column in the manometer varies rapidly, making an exact reading difficult or impossible. The peristalsis, moreover, draws upon the tube and the resulting sensations are very distracting. Further, the sensational complex is so complicated that the appearance of an additional factor in the form of a just noticeable pain is inherently difficult to determine introspectively.

Localization. The localization of these complexes of pressure and pain is shown in Figg. 51-70. The same phenomenon recurs that was observed with temperature, *i. e.*, a tendency to refer sensations in both directions away from the upper portion of the chest. A difference appears, however, in the fact that none of the pressure sensations are referred to points above the actual place of stimulation. In B and D, the two upper points are sometimes localized correctly. The lower points, although varying in height with the height of the stimulus, are placed very much too low. All the localizations of G and F are below the stimulus. F makes almost as great errors for the lowest point of the esophagus as for the upper points. Some of his localizations (not shown on the figures) were as low as the umbilicus.

Quality of Sensation. The character of the experience resulting from mechanical stimulation is shown by the following extracts from the reports of the observers.

B, 40 cm. Max. press. = 35. "Pressure first felt as below clavicle, 6 to 7 cm., or as up in top of back of throat,—the usual confusion. As pressure got more intense, it got more unpleasant. Suddenly I realized that this feeling was exactly the thing that gives warning when one is about to vomit. It is in nausea, but so far as I can tell is purely pressure."

B, 40 cm. Max. press. = 45. "At first pressure, very much like a dull pressure, *i. e.* subcutaneous pressure; very soon, however, it becomes dull and 'achy.' The ache is not definitely pain. It is the peculiar characteristic of these internal pressures, and seems more to color them than to be a separate component. The complex is something like the ache of muscular pressure, but more definite than I have ever felt in muscular pressure, unless it be in fatigue."

D, 40 cm. Max. press. = 35. "At first pressure; then felt sort of bloaty. Fullness contrasts with my feeling afterwards when the air is released."

D, 35 cm. Max. press. = 60. "Felt definite pressure below sternum and a tendency for the tube to pull down. Pressure then got more intense and 'achy;' resembled something that swallows hard."

F, 40 cm. Max. press. = 35. "Very pressury sensations in a small

[34] *Cf.* Hertz, *op. cit.*, 17.

lump, like a kind of a ball of muscular pressure. Intensity rises gradually; the sensations did not flash out."

F, 30 cm. Max. press. = 45. "Diffuse. This time the sensations were not so pressury; quite a good deal more intense; later the sensations went way up to the head and around and up to the nose." Q. "Pressure sensations?" A. "No. Much livelier than muscular pressure; more the quality that muscular pressure has when it gets quite sore and unpleasant; thinner and finer in diffusion than muscular."

F, 30 cm. Max. press. = 20. "Ball of muscular pressure below end of sternum stayed a little while and then disappeared."

G, 40 cm. Max. press. = 40. "At first pressure with slight coloring of pain localized in the ribs. Very funny. Both sides, sometimes front. A little later, the pain constituent becomes prominent, although not so very prominent."

G, 30 cm. Max. press. = 40. "At first pressure at sternum at middle line. Then pressure became more intense and a little crampy. Later it became very crampy and unpleasant."

G states after the series that "all these pressures are dull, heavy pressures like muscular pressure, not cutaneous in quality."

The introspections indicate that the esophagus mediates a pressure, which is like a muscular pressure, if not identical with it. In order to make the comparison more definite, the experimenter tried giving the esophageal complex and a complex produced by deep pressure on the arm simultaneously and in rapid succession. The observer swallowed the tube to 30 cm. Then the skin of the upper forearm was anesthetised by spraying with ether. A pressure, at the anesthetised portion, was produced by a Cattell algometer. Two sorts of trials were made; one, in which the intensity of the pressure on the arm was sufficient to bring out deep pain, and in which the amount of inflation of the bladder was sufficient to elicit the ache-like "crampy sensations;" and another, in which the intensities were weak enough to produce only pressure sensations in both esophagus and arm.

D, in comparing esophageal pressure of 60 cm. of water with an arm pressure of 3.5 kg., thought that the pressure sensations were identical in quality, although the one on the arm was more definite and less diffuse. The pains, he found, were both different from cutaneous pains. He was not sure whether they were alike. The pain from the arm was less like an 'achy' pain, was harder. His introspection upon the weaker intensities (30 cm. of water and 2 kg.) bears out his earlier report that the pressure sensations are alike in quality, although differing in extensive and intensive patterns.

F, after comparing 60 cm. of water in the esophagus with 3.8 kg., reports: "I can not find the slightest difference so far as the quality is concerned. The pain strains were of slightly greater intensity in the esophagus and were of wider extent."

After observing the weaker intensities (32 cm. of water and 1.8 kg.), F reported: "I do not know what I mean by thick and dull, but

certainly the arm sensation was much thicker and duller than the sensation in the esophagus, had much more body to it, was heavier. It seems to me as if the pressure in the esophagus went through a series of stages, from the weak pressure right up through the strainy, deep-pain thing, in more or less of a straight line, although you can tell when the pain comes; whereas in the arm you can pick out the place where the new quality appears."

G, after being practised in discrimination of kinesthetic sensations in the arm, is asked to compare 50 cm. of water in the esophagus with 2.5 kg. She reports: "Muscular pressure in chest with tendinous strain, forming a crampy complex. In the arm there was first muscular pressure. Then pain gradually began to be fused as it got stronger. The complex in chest was crampy in character."

With the weaker intensities (25 cm. of water and 1.2 kg.), G says: "In my arm I got a sort of muscular pressure; localized within; thick, not areal. In the chest there was a scrapy lump before blowing up. This became less, while muscular pressure gradually became clearer. At first it seemed like the pressure from the arm, and then became more distinctly muscular and, I think, tendinous. When the tendinous sensation came, it had a very slightly crampy character, a sort of strain."

It appears that D and F identify the pressure components of the esophageal complex unequivocally with muscular pressure in the arm. G observes that the esophageal pressure is more crampy in character, and is inclined to suppose that it must be of the tendinous order of pressures. We have already seen that F had difficulty in deciding whether the internal pressure was painful. His difficulty arose from the fact that the muscular pressure seemed to go over without sensible break into a painful pressure. It may be that G has the same difficulty. It is more probable, however, that she failed to experience the muscular pressure in isolation because (as she insists in her reports) the painful sensations from the end of the tube were never absent. G does not herself call the arm sensations muscular, but designates them as "deep pressure," in distinction from "muscular pressure," which approaches tendinous strain and which is found in the esophagus. B did not make the comparison between arm and esophageal pressures, but was convinced throughout that the pressure from the esophagus was of the same general order as muscular pressure.

All the observers agree that there is no qualitative difference between the sensations of pain from the esophagus and those from the arm, although they find very different extensive and intensive patterns. The pain in the arm is sharply defined and intense throughout; it is also often more definitely localized. The pain in the esophagus is much less definite in extent and less uniform in intensity.

3. *Electrical Stimulation.*

Sensibility. In these series, bipolar electrical stimulation (tube 7) was used in the manner and under the conditions described above (p. 10). All the observers were sensitive to electrical shock throughout the length of the esophagus. Four columns of Table VII show the approximate minimal intensities of break-shock required to produce a sensation. It will be seen that the sensitivity of the esophagus increases from the lower end up. The very small value for G at 40 cm. is possibly due to projection of the lower pole below the lower end of the esophagus. G's esophagus probably does not in any event extend below 41 cm. from the teeth; and since the measurements were taken to a point midway between the two poles, the lower pole would have been more than 40 cm. down.

TABLE VII

Sensibility of the esophagus to electrical stimulation. Figures show the intensities of shock in Kronecker units (8 volts primary circuit) which brought out a just noticeable sensation. The last column gives a set of equivalent intensities for observer B.

Position of Stimulus	Intensity of induction shock in Kronecker units				
	For just noticeable sensation				For equivalent intensities of sensation
	Observers				Observer
	B	D	F	G	B
40	3750	3750	3750	10250	3400
35	2600	3750	3750	2600	2800
30	2600	3750	3750	2600	2350
25	1500	1500	700	1500	2350
20	700	1500	700	700	1300

In a subsequent series for localization (p. 36), the writer found it necessary to determine the equivalent intensity of electrical shock for the different parts of the esophagus. This determination was made with the apparatus for localization without knowledge (tube 8; see p. 7). A setting of the secondary coil at 2,800 units was found to give a shock which was fairly intense but not uncomfortable. Accordingly, 2,800

at 35 cm. was selected as a standard. Series were taken in which the other points were compared with this standard. In every case, the intensity of the point compared was varied from weaker to stronger, and also from stronger to weaker. The order of variable and standard was reversed at random, so that the observer was not prejudiced by knowledge of conditions. The variations were made by 2 mm. steps upon the scale of the inductorium (equivalent to about 100 Kronecker units). In practically all cases, the points of equality in the ascending and descending series agreed, and were selected as the stimulus value corresponding to equivalent intensities. They are given in the last column of Table VII. They indicate further that the sensibility of the esophagus increases toward the upper end; and that the increase is rapid at both ends and very small in the middle region.

The large number of units required to produce a just noticeable sensation indicates the high absolute limen of sensitivity of the esophagus. We have noted above (p. 11), in discussing the impossibility of using unipolar stimulation, that the periphery, even with a relatively larger electrode, is very much more sensitive than is the esophagus. This statement applies only to the lower portions of the esophagus. The upper portions are probably as sensitive as the skin, if not more so. A just noticeable sensation upon the skin occurs when the coil is set at 1,500, and the fingers are moistened and held firmly on the terminals.

Localization. The localization of these sensations is shown in Figg. 71-95. With B and D the reference seems to be much the same as for pressure and temperature (Figg. 9-13). The error of localization is such that the indicated points do not lie upon the upper chest, but upon places above or below. F, with weak stimuli, gives a similar result. G shows a remarkably small error, even indicating two positions on the chest correctly.

With intense stimuli in the upper region of the esophagus F notices sensations in the upper arm. D also refers a moderately intense stimulus at the same place to the fingers. With intense stimuli in this region B regularly feels shocks in the fingers and in portions of the arm (most frequently in the upper arm, less frequently in the shoulders).

It may be objected that the spread of the current, and the stimulation by an electrical shock of nerve trunks at points other than their terminations, render this method ill-adapted

for a study of localization; and it may be added that some of the shocks are obviously localized far from the seat of stimulation. But the shocks in the arm are so different in character from the pressure-like sensation elicited by a weak shock in the esophagus that confusion is unlikely to occur so long as the stimuli are weak.

Quality of Sensation. The following extracts from the reports show the quality of sensation brought out by a weak electrical shock. Intense shocks gave complexes quite as difficult to describe as those aroused by intense shocks on the surface of the body.

B, 40 cm. Coil = 4950. "A different sort of catchy pressure, dull and 'achy.' I think that I have exactly the same sensation in swallowing something too large."

B, 20 cm. Coil = 4950. "Pressure faint and tiny; finer, narrower, brighter, and more cutaneously alive than before; more definite and also more like other peripheral experiences."

D, 40 cm. Coil = 4950. "Pressure, somehow mingled with pain. A catch, rather unpleasant."

D, 30 cm. Coil = 3750. "Quite a bit like swallowing something hard; seemed to extend up and down for an inch and a half."

D, 20 cm. Coil = 3750. "Different from all the rest; more like an electrical shock." Q. "Can you say anything about the quality?" A. "Like a very hard pressure; something like being up against a corner; a little bit of numbness."

F, 40 cm. Coil = 3750. "Sensation of very weak absolute intensity. Fine lines of sensation, rather than an area of quality; like the jerky muscular sensation that you get when a muscle is suddenly contracted electrically or otherwise: something very close to strain in it; because it is strain. I think there is a background of sensations spread over the whole area, but it is very weak indeed and very diffuse. I can hardly be sure it is there,—like the ticking of a watch far away. The quality is dull. It seems as if to describe it as a little 'organic stir' was right, especially as this is the sort of thing one has when one is stirred or affected."

F, 25 cm. Coil = 2600. "Sensation is more of the strainy kind than anything else in the world." F again insists on the affective character of these sensations and describes them as "excitement" or a "stir up."

G, 40 cm. Coil = 10250. "Muscular sensation over very small area; intensity rather weak; meant a twitch."

G, 25 cm. Coil = 3750. "Quality is little different. Pain component was present; darting. Whole thing seems to have finer texture, so to speak. Distinctly a little throb, with a lancing, darting pain." G implies later that muscular sensations are involved in the throb.

It is clear that electrical stimulation does not bring out any new qualities of sensation. On the other hand, the results support our conclusion that the esophagus is sensible to

pressure throughout its length; for these complexes are all formed of pressure and pain.[35]

4. *Chemical Stimulation*

All the experiments with chemicals were performed solely on observer B.

Alcohol. Five cc. were administered in each trial with tube 2. The esophagus appears to be sensitive to stimulation by alcohol throughout its length. Ten *per cent.* alcohol brought out sensations at 35, 25, and 20 cm., and heat at 30 cm. Cold was also felt in the throat at all these places and also at 40 cm. Warmth, however, did not appear at 40 cm. Thirty *per cent.* alcohol gives warmth combined with stinging sensations at 40 cm. Slight warmth was felt in the upper parts of the esophagus for a 4% solution; and even a 2% solution gave very slight warmth at 30 cm.

The localization of typical sensations for different intensities of alcohol is shown in Figg. 96-101. Fig. 99 shows the tendency for the sensation to spread. The final stage in Fig. 99 doubtless occurs when the alcohol reaches the stomach.

The character of the experience dependent upon stimulation by alcohol may be shown as follows.

B, 30 cm. 30% alcohol. "At first coolness. Then warmth develops and gets very slightly hot. It spreads as an intense warmth with a heat component. It is well below the surface of the body and uniform over the whole area. It shrinks from the chest up toward the throat until there is just a large general warmth, left in the throat."

B, 30 cm. 10% alcohol. "Decided cold in throat at first. Then a momentary heat in throat together with a little catch of heat opposite the nipples. Then nothing; and then a burning glow in throat, *i. e.* a diffuse, indefinitely localized heat. The heat becomes intense, so that the whole upper part of the middle of the body seems to glow with it. It seems then to shrink from below up and is soon confined to the throat only. Next it gets gradually weaker, and disappears at the time that a very strong, stinging heat develops over a large area in the stomach region. This heat dies down quickly until there remain only weak intermittent glows and stings."

Hydrochloric Acid. Five cc. of 5% HCl were introduced through tube 2 into the esophagus at 40, 30, and 20 cm. from the teeth. The esophagus responded in all cases with an ache-like or a stinging pain, generally very faint. These pains were localized either in the throat or somewhere below the level of the nipples. Portions of the reports follow.

B, 40 cm. 5% HCl. "Very dull ache of the tooth-ache kind, back

[35] The descriptions are not unlike those of Becher's Herr W., although our observers do not report a qualitative difference between the two ends of the esophagus. Becher says: "In der ganzen Speiseröhre ergeben sich sehr deutliche Sensationen. Doch ist der Eindruck nicht überall der gleiche. . . . Im oberen Teile der Speiseröhre hat Herr W. ganz deutlich den Eindruck des Elektrisierens, also jenes charakteristischen Schwirrens. . . . Im unteren Teile bleibt nur noch eine schwach brennende oder ätzende Wirkung, die Herr W. mit der eines scharfen Salzes, eines beissenden Gesmacksreizes vergleicht." (*Zeitschrift*, 49, 352.)

of the nose; then a stinging ache, *i. e.,* a raw feeling, in the throat. This ache goes quickly; then there is a much stronger ache, which is also 'stingy,'—a sort of burn without warmth. It becomes quite intense and dies away very slowly, fusing with general ache in stomach region. This latter ache gets more intense and presently without qualitative change turns into hunger."

B, 30 cm. 5% HCl. "Intense cold in throat. Then a stinging feeling above stomach, which was more like pain than a dull ache. Shortly afterward a dull ache appeared in the same place and also lower down, and turned presently into hunger pains."

B, 20 cm. 5% HCl. "Cold at first, then stinging pain from nipples to sternum. Then intense aching pains in stomach, rather sharp, bright, and diffuse. The ache later gets quite acute, like some of the pains in the call to defecation. Still later there is nausea, which involves both this ache and certain muscular sensations."

Mustard. In this series, 25 cc. of a 20% mixture of English mustard and water were injected into the esophagus. Aside from sensations of coolness and warmth, localized in the throat, very faint, and of very short duration, the esophagus does not seem to be sensitive to mustard; although characteristic experiences involving nausea, general aches, and specific burning aches in the throat, occur approximately at the time that the mustard reaches the stomach.

Pepper. In this series 25 cc. of powdered black pepper in suspension in water (1:100) were used. In each case a coolness is felt at once in the throat; later stinging sensations are also felt in the throat. The stinging sensations are the more delayed, the farther up in the esophagus the pepper is applied. Consequently we may assume that they come from stimulation of the stomach.

Peppermint. A 2% dilution of oil of peppermint in olive oil was used. Five cc. were injected. The introspections indicate that the esophagus does not respond to oil of peppermint. The warm sensations occur after the oil has had time to reach the stomach. Olive oil alone brought out no response.

(Numbers in brackets indicate the number of seconds elapsed after the administration of the stimulus.)

B, 40 cm. 2% oil of peppermint. "[16] Cold around the sternum; then a slight burning sensation in the throat, which soon disappears. [33] Cold around sternum gradually extends on up with slight ache."

B, 30 cm. 2% oil of peppermint. "Cold in throat at once. [23] General stinging cold; turns gradually into a warm glow all along median line. [49] Glow gets very intense, a diffuse heat. No more cold. The glow is intense all the way from top of larynx to just below sternum. It dies away in throat last, and as it dies away a cold reappears."

B, 20 cm. 5% oil of peppermint. "At first, very cold in throat. [35] Faint ache in stomach. [37] Burning heat in throat begins, and gets quite intense, but does not spread below throat; lasts a long time. [230] Heat is now dying out. Some cold has returned."

5. *Localization*

It has already been shown that esophageal sensations are variously localized by different individuals and, under different conditions, by the same individual. In general, the

reference is downward for most of the sensations from the lower two-thirds of the esophagus, and the points of reference tend to group themselves, so that the error of localization is greater for higher points of stimulation. The upper third of the esophagus, however, is apt to give sensations localized above the point of arousal. Stimulation of the lower end of the tube often results in sensations in the throat, concomitant with those higher up, and either of the same or of a different quality. In the series that we are about to describe, an attempt was made to measure the errors of localization. In all cases so far mentioned, the data have been obtained by the use of a stimulus tube with but a single place upon it for stimulation; the tube had to be moved up and down the esophagus. It was impossible to keep the observer in ignorance of the position of the tube. Even had he obtained no cues from the serial method followed, or from the length of tube outside of the mouth, he might still have obtained them from the ache-like sensations aroused by the end of the tube. For these reasons tube 8 was so constructed that it could be left in the esophagus and stomach, and electric shocks could be given at various points without altering its position.

It first appeared that the esophagus was unequally sensitive at different portions of its length; so that, when equal intensities of shock were used, an intensive cue to the point of excitation was afforded. B, the only observer, knew that the lower end of the esophagus was in general less sensitive than the upper end, and was therefore inclined to look for the weaker shock in the region of the sternum. For this reason, equivalent intensities for the different parts of the esophagus were determined in the manner described (pp. 31f.). We had planned to include a point of stimulation in the stomach, and had therefore attached the sixth pair of terminals at the end of the tube. There was, however, so marked a difference in the contact made in the stomach at various times (due, probably, both to the chance position of the end of the tube and to the nature and amount of the stomachic contents), that it was impossible to get the same intensity of sensation from the same intensity of current. Since these high intensive differences were further complicated by variation in quality, we decided to exclude the stomach from this series of trials.

Twenty-five series were arranged, in each of which each of the five points in the esophagus occurred once in haphazard order, determined by drawing numbers from a box. The observer lay supine, blindfolded, and with arms stretched at his sides. Localization was made by bringing the right hand up to the body after the shock had been felt, and indicating the point with the forefinger. The observer was allowed to move the hand after he had touched the body. In a preliminary series it was found that there were a certain number of very indefinite sensations, which the observer experienced great difficulty in localizing. Hence, in the regular series, he was allowed to ask for the repetition of the stimulus when he felt very

uncertain as to its position. Sensations that seemed to cover an area, or to stretch out in length, were localized at the point which appeared to the observer as the middle.

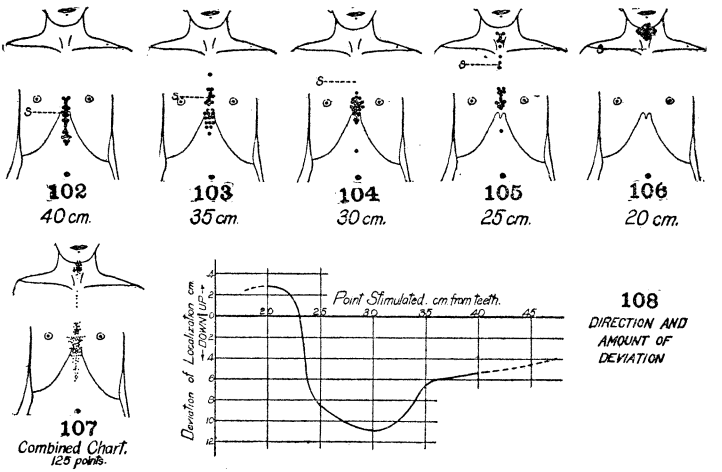
TABLE VIII

Localization of electrical stimulation of five different points in the esophagus. All figures, including the column headings, which indicate the point of stimulation, represent cm. along the alimentary tract from the teeth. The values are rearranged to show the distribution.

Point Stimulated	40	35	30	25	20
	48.5	46.	49.	45.	24.
	48.	43.5	42.	38.	16.
	48.	43.5	41.	37.	15.5
	48.	42.	41.	37.	15.5
	47.	42.	40.5	36.	15.
	47.	42.	40.	36.	15.
	46.	42.	39.5	36.	15.
	46.	41.	39.5	35.	14.5
	45.5	41.	39.	34.5	14.5
	44.5	40.	38.5	33.5	14.5
	43.	40.	37.5	33.	14.5
	42.5	40.	37.5	33.	14.
	42.5	39.	37.	32.5	14.
	42.5	39.	37.	32.	14.
	41.	37.	37.	32.	14.
	41.	36.5	37.	26.	14.
	40.	36.5	36.5	24.	13.5
	40.	36.	36.5	22.	13.5
	39.5	35.	36.	18.5	13.5
	38.5	34.5	36.	17.	13.5
	38.5	33.	36.	17.	13.
	38.	32.5	34.5	16.5	13.
	36.5	32.	34.5	15.5	12.5
	36.	32.	34.	15.	12.
	36.	27.	33.	15.	12.
Average.....	42.52	38.12	38.00	30.68	14.42
Av. error.....	2.52	3.12	8.00	5.68	5.68
M. V.....	3.38	3.77	2.40	7.60	1.27
Av. error.....	.....	.....	.....	10.33 6.35	
M. V.....	.....	.....	.....	2.32 3.19	

The localizations are shown in Table VIII, in which the values are rearranged so that their distribution is evident. The M. V. for 25 cm. is very large. Its size is due to the fact that the points fall into two groups, the one considerably above the point of stimulation, the other very much below. If the points are arbitrarily separated into these two groups,

so that all above 32 are in the one and all below 26 in the other (there are none between 26 and 32), the M. V.'s are greatly reduced. The figures for this separation are shown below the last line in the column for 25 cm.



FIGG. 102-108.—LOCALIZATION OF ELECTRICAL STIMULI IN THE ESOPHAGUS

102-106. Points of reference for 25 stimuli at each of 5 positions, *viz.*, 40, 35, 30, 25, and 20 cm. from the teeth. 107. Combination of 5 preceding diagrams. Note reference away from upper chest. Points show longitudinal, not transverse, reference. S = level of stimulus. 108. Curve, showing amount and direction of reference.

Diagrams for each of the five points of stimulation are shown in Figg. 102-106. The position of the points in these figures is correct longitudinally, but not transversely, since almost all were localized on the median line (only one point was localized more than 1 cm. to one side). Fig. 107 is a combination of the five figures preceding, and shows the longitudinal position of all the 125 points. Fig. 108 shows these amounts of deviation (*i. e.*, the average errors) platted in the form of a curve. The curve is steep below 25 because there are few localizations in this region. The dotted lines indicate a probable extension of the curve.

The result is what we had expected from the rough localizations of the preceding experiments. Reference is away from the upper portion of the chest. This fact was recognized, at least by B and F, in their introspections. B constantly

complained that inside himself he "had no neck;" that is to say, he felt sensations in his throat and in the region of the sternum, and believed them to be part of the same complex, although they did not seem to be localized in the intermediate region. B explained the continuity by saying that the sensations were continuous when visualized from within, but they were discontinuous when visualized as underlying the various parts of the body. The difference was very striking: when he visualized from the outside, there was a constant fluctuation of the visual image (more often an alternation than a co-existence); but, when he visualized from within, not only was there but a single sensation to be found, but there seemed to be nothing else to which he could attend. Apparently the spatial pattern within the chest does not correspond with that of the outside.

On the basis of these results we cannot agree with the statements of Becher. Concerning cold and warmth sensations in the esophagus he writes: "Die Lokalisation— in der Höhendimension und nach einer obigen Bemerkung über die Feststellung der unteren Linksabweichung auch in der Breitendimension—ist innerhalb gewisser Grenzen zuverlässig."[36] "Herr W. empfindet also zweifellos in der ganzen Speiseröhre Druck- und Berührungsreize. Diese werden ziemlich gut lokalisiert."[37] For electrical stimuli, "das Lokalisieren ist ziemlich gut, wie bei den Druckreizen."[38] Hertz is even more positive and states "that the whole esophagus is sensitive to thermal stimuli, and that the power of localization is extremely accurate, particularly in the case of heat."[39]

The tendency to refer the sensations which originate in the esophagus in the region of chest to the soft parts of the trunk may throw some light upon the means by which ability to localize is acquired. Our experiment requires the observer to localize sensations from the esophagus upon the surface of the body. The only parts of the body-wall on which a stimulus, affecting the surface of the body, would also affect the esophagus, are the soft parts below the sternum and above the clavicle. These parts may thus have become associated in experience to the corresponding parts of the esophagus. The probability that stimuli below the sternum would affect the esophagus farther up under the hard chest-wall than the stimuli at the neck would affect it downward and underneath may explain the facts (1) that sensations underneath the chest-wall are referred a greater distance downward toward the sternum than they are upward toward the neck, and (2) that the part of the esophagus below the upper chest is

[36] *Zeitschrift,* 49, 352.
[37] P. 351.
[38] P. 352.
[39] *Op. cit.,* 6.

the seat of the most indefinite sensations, those which are the hardest to localize. If the observer could in some way reach down his esophagus and touch the actual point stimulated, as he may do in localizations upon the skin, it seems probable that the accuracy of localization would be found to be much greater.[40]

III. The Stomach

1. *Thermal Stimulation*

Sensibility. The stomach was stimulated with 25 cc. of water at various temperatures. Subsequently a special series with varying temperature was taken with the aim of determining whether the stomach is sensitive to cold or warmth, and, if so, at what temperatures. In this series 50 cc. of water were used. The combined results of all observations are given in Table IX. The grouping of observations made

TABLE IX

Sensibility of the stomach to temperature. Delayed sensations (probably due to the spread of the stimulus) are placed in parenthesis.

Stimulus Temp., °C.	Observers			
	B	D	F	G
0	cold	cool	cold	cold
10	cold	no temp.	no temp.	cold
19	cold			
20	cold	no temp.	no temp.	cold
23	cool			
27	cool			
30	cool	no temp.	no temp.	cold
31	no temp.			(cool)
25			no temp.	(cool)
39				(cool)
40	no temp.	no temp.	no temp.	
47	no temp.			(warm)
50	heat	no temp.	no temp.	warm
51				(warm)
55	heat			
60	warm	(warm)	no temp.	heat
70	heat	(warm)	warm	warm-heat-pain?
80	heat-pain			

[40] Meumann suggests that the esophagus might become educated in localization by the successive sensations occurring in the swallowing of food (*Archiv*, 14, 288f.). He does not seem to realize that the kind of localization under consideration requires that there should be an association between the internal sensations and processes representing the exterior. Becher has criticized his position (*Archiv*, 15, 358f.).

with different amounts of water and in different orders is justified by the fact that the stomachic conditions are never constant (from variation of stomachic contents), and also by the remarkable consistency of the data. Only those sensations that followed immediately upon stimulation are recorded, save in cases when no temperature sensations occurred until late. The quality of the delayed temperature sensations is entered in parenthesis.

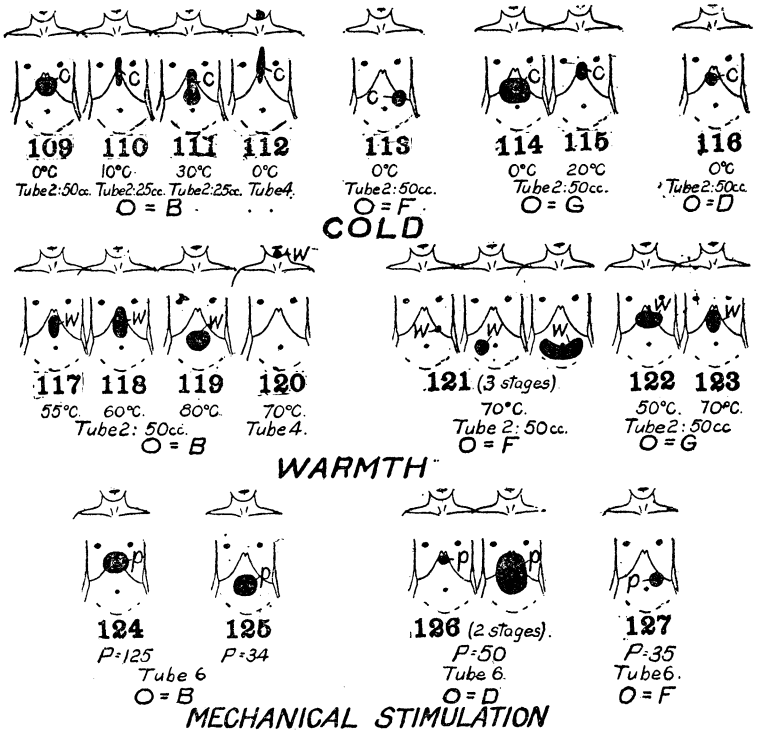
All the observers are sensitive to cold at 0° C. B feels cold at 20° and coolness at 30°. G feels cold at 30°. The delayed coolness that G finds for temperature as high as 39° may be due to conduction to the body-wall.

If we consider the delayed cool of G as not aroused in the stomach, then for all the observers there is a *Nullpunkts-temperatur.*

B once reports heat at 50°, although the result could not be duplicated. He always finds heat or warmth at 55° or 60°. G reports heat at 60° and warmth and heat at 70°. F finds warmth at 70°. D does not find either heat or warmth, except after some delay, for 70° or less. The experimenter hesitated to go above 70°, except in his own case, for fear of injuring the tissues. B finds thermal pain at 80°, and G suspects it but is not sure of it at 70°. We may say in general that B, F, and G appear to be sensible to warm stimuli, and that D shows no such sensibility within the limits of the experiment.

The sensibility of the stomach to cold and warmth was also demonstrated in B by the use of the water coil (tube 4) at 0° C and at 60° C. The electric heating coil (tube 3) did not give definite warmth at all.

Localization. The localization of cold from the stomach is shown in Figg. 109-116, and the localization of warmth or heat in Figg. 117-123. The points to which cold is referred seem approximately correct, though they are on the average too low. The localization to one side in Fig. 113 may be due to the actual position of the tube in the stomach, although F showed an individually marked tendency to refer incidental internal sensations to this side. Figg. 119 and 121 indicate the spread of the warmth. In Fig. 121 it is not unnatural that, in spreading, the warmth should no longer remain at the side, although it is surprising that it should lie entirely below the umbilicus. The only sensations referred to the throat were those of B (Figg. 112 and 120), in which the water coil (tube 4) was substituted for tube 2.



FIGG. 109-127.—LOCALIZATION OF THERMAL AND MECHANICAL STIMULI IN THE STOMACH

O = Observer; P = maximum intensity of pressure (cm. of water). c = cold; p = pressure; w = warmth.

Quality of Sensation. There can be no doubt that the cold experienced upon stimulation of the stomach is qualitatively like cutaneous cold. It is sometimes more peculiarly sharp and intense than the ordinary cold felt on the skin, and more like that from the glans penis. B describes the cold as "quite intense, sharp, very bright and pleasant, quite different, like paradoxical cold." D mentions only a "slight coolness." F reports "cold sensations, weak in intensity, overlying and in front of the bubbly sensations." G speaks of "sensations of cold, very clear and fairly intense," and later of a "more intense cold, low and narrow, combined with a weaker cold near waist line." She adds that she could not tell exactly where the boundaries of the areas were.

In order to get a comparison of the qualities of cold from the stomach and from the skin, the following experiment was arranged. The stomach tube was taken into the stomach, and a hot-water bottle wrapped in a cloth was placed on the abdomen and connected with another tube. Water was pumped into the bottle and into the stomach at the same time. At one time, cold water was pumped into the stomach, and water at body temperature into the hot-water bottle. At another time, the neutral water was given inside and the cold water outside. The observer described his experience. In the first trial, with the cold outside, B, the only observer, thought first that the cold came from the stomach; but later, when it had spread over a larger region than was usual for stomachic colds, he identified it as originating in the skin. When the temperatures were reversed, he was at first uncertain as to the origin of the cold, but later identified it as internal, because it was duller, heavier and less bright: adjectives which, he says, indicate a temporal, spatial, and intensive, but not a qualitative difference.

In a second trial cold water was injected simultaneously into the stomach and the hot-water bottle. B recognized the internal cold as coming first because it was accompanied by the typical reference of cold to the throat. He also believed that the external cold lasted longest because of the large area affected at the end of the trial and because of the pressure cues from the bottle. He was totally unable, however, to say at what point the internal cold passed over into the external or whether they both existed together at any time, and declared that the two experiences were identical in quality.

We may question the origin of the sensations of cold in internal stimulation in the stomach; but there can be no question that, wherever they originate, they are in quality like the sensations from the skin.

The sensations from hot stimuli are described both as heat and as warmth. B, for example, reports: "Heat suddenly begins and spreads in most alarming fashion; gets more intense and spreads rapidly (see Fig. 119). Almost felt as if whole front of my body were hot; like a flat sheet of heat a little below the surface. Very 'stingy,' bright and piercing, but not truly painful." Again he reports: "Besides the pressure, there is warmth from sternum down; then a general heaty warmth in the stomach region, almost burny, not so unlike pepper. After the trial, there is a general warm glow for some time." D, after an 8 sec. interval, reports a "warmth;" after 15 seconds, "different warmth;" after 32 seconds, "almost hot;" after 43 seconds, "still warm;" and after 78 seconds, "very indefinite, becoming a general glow." F, who had felt no warmth at all below 70°, found at this temperature a "little spot of warmth, quite warm, as small as the end of my finger," which "quite slowly spread over a large area. The more intense part of it forms a core about twice the size of a dollar." G states that there are "warm sensations to begin with, which become quite hot. They are located in the stomach; the area is longer than wide. They

become diffuse as time goes on, and are located more and more toward outside of body."

The experiment with the hot-water bottle described above was repeated with water at 37° and at 60°. The observer (B) was not deceived as to the location of the warmth, because on the outside the warmths were felt to agree spatially with the sensations of pressure from the bag, and on the inside, heat sensations were felt in the throat. B suspected, however, a qualitative difference between the two; the internal warmth seemed duller, more diffuse, and had something of the character of an ache in it. When warm water was injected both inside and out the internal sensations were interpreted as preceding the external, principally, as was the case with cold, because the sensations referred to the throat were felt first and the pressure of the hot-water bottle last. In the middle of the course the observer could not distinguish between the two complexes nor state where one began or the other left off. All the warmth was localized in the same region about the same distance beneath the surface of the body. The early warmths were more heat-like and more diffuse than the later ones. The presence of heat or even of an ache does not, however, argue for a qualitative difference, but merely for a greater effectiveness of the stimulus in the one case. Diffuseness may be spatial, dullness intensive. It is not conclusively shown that there is any qualitative difference at all.

Seat of Sensation. There can be little doubt that many of the delayed sensations following thermal stimulation of the stomach originate in the nervous organs situated elsewhere, perhaps in the skin or the body-wall. Often a warmth or a coolness will occur some time after the stimulation, and will spread well over the body, the whole temporal course occupying a minute or more. Whether the immediate sensations can be attributed to the stomach is not entirely obvious, especially as there is no qualitative difference between internal and external cold, and as the apparent difference in the case of warmth may be due to the fusion of an internal 'ache' with an external warmth. The extreme temperatures from 50° to over 70°, which are necessary to bring out the warm sensations immediately, may mean that no warmth can be felt unless the conditions are such as to promote rapid conduction. In favor of the position that temperature sensations depend upon conduction away from the stomach to more superficial tissues is the fact that their delay is decreased by increasing the temperature from 50° to 80°. Finally the qualitative similarity—not to say identity—of the experiences dependent upon external and internal thermal stimulation is evidence for their common seat. The case is perhaps still unproven, but the writer inclines to the belief that the actual tissues of the stomach do not mediate the sensations of cold or warmth,

but that these sensations arise upon internal thermal stimulation by conduction to the body-wall.[41]

2. *Mechanical Stimulation*

Sensibility. In all observations both pressure and pain sensations were elicited by inflation of the bladder of tube 6. The intensities, expressed in cm. of water required to produce a just noticeable pressure and a just noticeable pain, are as follows:

	B	D	F	G
Pressure.	12	10	20	25
Pain.	35	50	35	35

It is again difficult to state whether these sensations originate in the stomach or whether they come from surrounding tissues as the result of distension of the stomach. In extreme inflation, the pressure spreads down into the abdomen, and when the air is released there is a general feeling of relaxation. These sensations undoubtedly come from the body-wall, and possibly from other organs, and there is no assurance that the lighter pressures are not also mediated by the surrounding tissues.[42]

Localization. The localization of pressure in the stomach is shown in Figg. 124-127. The reference is usually to a point below the stomach, sometimes to one as low as the umbilicus. This fact is in accordance with the belief of most people that the stomach is well down below the ribs, as well as with the recent anatomical conclusions.

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[41] This conclusion is in accord with those of Becher (*Zeitschrift,* 49, 350), Hertz, Cook, and Schlesinger (*op. cit.,* 483), and of Hertz (*op. cit.,* 7), although the last writer admits that the stomach may "rarely" be sensitive to heat and cold (p. 9). The present writer plans a further detailed study of this point for the future.

[42] Hertz states that the stomach is insensitive to tactile stimulation (*op. cit.,* 3), but that the sensation of 'fulness' is experienced at a pressure of about 18 cm. of water (p. 19), a value that accords closely with our own. Becher, however, insists that the stomach is insensitive to pressure and that the sensation of fulness is due to expansion of the body-wall (*Zeitschrift,* 49, 356f.). Meumann speaks of "eine charakteristische Empfindung von Fülle und Druck im Magen" (*Archiv,* 9, 52f.), but probably does not mean typical pressure. He is interested chiefly in the *Verdauungsgefühle* and takes pains to distinguish the sensations of *Fülle* and *Leere* from the *Druck- und Zugempfindungen* of the skin of the abdomen and also to separate the feelings of *Fülle* and of *Sättigung* from each other (*Archiv,* 14, 292, 295). He ascribes hunger partially to the stomach (*Archiv,* 9, 152).

Quality of Sensation. The following reports were made upon the quality of the stomachic sensations.

B, Max. press. = 25 cm. "Dull ache, fairly well down; distinct from the mere pressure sensations above. The ache is sharply painful, but is something like a sensation from an object stuck in the throat. It seemed perfectly simple and elementary, and like pressure plus pain. It is something like hunger, but more diffuse and cloudy. The boundaries are indefinite."

B, Max. press. = 34 cm. "At first I begin to feel pressure. General distension got gradually more intense and very definite; similar to sensation of fullness after a big meal and somewhat like cutaneous pressure, *i. e.,* not at all 'achy.' Quite definite. Perhaps it is cutaneous pressure; my body-wall feels bulged out. Later, I feel as if I were going to burst. I think the sensations on release of pressure are entirely cutaneous."

D describes the stomach pressure as "large" and "bloaty."

F, Max. press. = 30 cm. "Very weak muscular-pressure-like sensation. Then I got a pole of pressure just a little to the left and above umbilicus, moderate intensity. Pole increases in intensity and gets larger. Finally gets painful. Pressure very intense. Pain more scary than intense. Made me break into sweat. Strain sensations came in somewhere quite superficially, way up near the sternum; a bit colicky and more superficial than the strain sensations accompanying the pain above. Could feel the outside body-surface expand; probably tactual sensations."

G gets slightly painful sensations of "crampy nature, neither stabbing nor sore," finally however becoming "definitely crampy and muscular."

It is evident we have found no new quality of sensation by mechanical stimulation of the stomach. The pressures and dull pains are of the same order as those felt in the esophagus and, to a certain extent, below the surface in any portion of the body.

3. *Electrical Stimulation*

Sensibility. The stomach proved to be variously sensitive to electric shock with tube 7. The minimal stimulation occurred within the following intensities (Kronecker units); the variation was due to chance differences of contact in the stomach or of the short-circuiting effect of the acid in the stomach.[43]

B	D	F	G
3750-7600	6250-10250	3750-4950	4950-10250

Localization. The localization of these sensations is best shown in the results of a special series upon B. Tube 7 was used and the coil was set at 4950 units. Stimulations were given with the tube at 45, 50, 55, and 60 cm. from the teeth,

[43] Becher reports that the stomach is insensitive to electrical stimulation (*Zeitschrift,* 49, 356).

five trials in each position, twenty in all. The tube was pulled up and forced down each time and the positions were selected in a random order. The results, which show a degree of uniformity greater than that for the esophagus, follow.[44]

Position of tube.....	45	50	55	60
Average localization	38.2	42.8L3.6	50.2L3.6	51.8Ro.6
Mean variation	1.0	1.3L1.1	1.0Lo.5	1.8R2.5

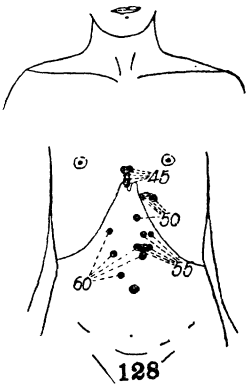

FIG. 128.—LOCALIZATION OF ELECTRICAL STIMULI IN THE STOMACH

Points of reference for 5 stimuli for each of 4 lengths of tube within the stomach, *viz.*, 45, 50, 55, and 60 cm. from the teeth.

Fig. 128 shows the localizations diagrammatically. The exact error of localization can not be determined because the exact position of stimulus is indeterminable. Neither can the position of the stomach be stated with certainty,[45] nor can the course of the tube within it be known. The localizations, however, for a given length of tube group themselves quite closely, those for the longest lengths lie farthest from the cardiac region, and the course of variation—first downward and then to the right—is that which might be expected in the most usual stomach.

[44] Meumann has already maintained that with palpation one may come to localize the stomachic sensations very definitely (*Archiv*, 9, 52).

[45] "There is no organ in the body the position and connections of which present such frequent alterations as the stomach" (Gray, H., Anatomy, Descriptive and Applied (Spitzka), 1913, 1005). Recent radiographic work has shown that the stomach may frequently extend as low as the umbilicus or even entirely below it, and that both position and size vary very greatly with the individual and with internal conditions in a single individual. *Cf., e. g.,* the radiographs reproduced by v. Elischer, J., Ueber eine Methode zur Röntgenuntersuchung des Magens, Fortschr. a. d. Geb. d. Röntgenstrahlen, 18, 1912, 333ff. No wonder that Herr B. in Becher's experiment appeared to localize "sogar fast unterhalb des Magens."

Quality of Sensation. The observers had great difficulty in describing the quality of intense induction shocks. The weak ones were, however, described as faint catches or jerks, and the observers all inclined to the belief that there was no difference from the sensations that would be felt under similar conditions on the periphery. The shocks were much brighter and less ache-like than those in the esophagus.

It may seem that the production of kinesthesis-like sensations in the stomach by weak electrical shocks argues for the sensibility of the stomach itself. The proof, however, is not positive; for the more intense shocks sometimes made the body wall twitch; and no shock greater than 3750 units can well be considered as so weak that it would be unlikely to spread (see p. 32).

4. *Chemical Stimulation*

Alcohol. Various concentrations of alcohol were blown into the stomach with tube 2, five cc. at a time. Faint warmth was felt for 60% and also for 100%. With the latter, coolness was felt below the sternum at first, and then a very faint warmth, which is a little like heat, that is to say, a faint burning which shifts intermittently over a fairly large area. Later, there is "an uncomfortable feeling," which consists of a dull ache and a pressure, such as one has when sick at the stomach, only much fainter.

Hydrochloric Acid. Both 5% and 10% HCl produce, in the stomach, sensations very much like those constituting the ache of hunger. B reports for 5% "hunger, or a strong intense or diffuse ache, getting fainter."

Twenty *per cent.* HCl produces dizziness in the head, in the region in which the "ice-cream pains" are localized, warmth in the face, a feeling of tenseness in the region of the stomach, a vague ache in the same region, and tingling, 'achy,' 'nervous' sensations in the arms.[46] Later the ache in the stomach changes, and is recognized as nausea, although its similarity to hunger is also noted. In fact, the observer thinks that the difference between hunger and nausea is not qualitative.[47]

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[46] Hertz, Cook, and Schlesinger do not find the stomach sensitive to HCl (*op. cit.*, 486); but Becher mentions several experimenters who obtained sensory responses with fairly strong solutions (*Archiv*, 15, 365f.).

[47] The writer has been at some pains to gather introspections upon hunger, nausea, thirst, and other organic experiences. He reserves their publication until such time as he shall be able to prepare a more thorough introspective study of organic sensations. The adequacy of HCl as a stimulus to hunger suggests that it must set up the hunger contractions (*cf.* Cannon and Washburn, *op. cit.*, and Carlson, *opp. citt.*). The present writer found that HCl in the intestine produced contractions and the call to defecation. Cannon, however, says that it produces normal peristalsis in the stomach and stops hunger.

Mustard. B swallowed six capsules, each containing one-half gram of mustard, at intervals of two minutes. At first, there were aches in the upper part of the esophagus, very dull and pressure-like. Later came pains and swimming sensations in the head, referred principally to the eyes and to the back of the head. Next the ache in the esophagus became intensely warm and assumed a very uncomfortable, insistent, burning character. It was shot through by a core of sharp stinging burns localized in the throat. Next came muscular sensations in the throat, "as if the esophagus were stopped up." Later the dull 'achy' pains spread to the arms, the heart, and other deep parts of the body.

Pepper. B swallowed successively at two minute intervals six capsules, each containing one-third of a gram of black powdered pepper. This experiment resulted in warm sensations in the throat above the clavicle. The sensations were faint, but very 'stingy.' Later the warm got more intense, and was accompanied by an 'achy' pain, also referred to the throat. Much later, it became hot. The heat and pain extended all the way from the throat down to the region of the stomach, remaining however much more intense above. The heat complex, which was very much like a cutaneous heat, including the usual 'sting' and occasional brighter 'shots' of pain, lasted a longer time. Even half an hour later, when it had become intermittent, heat returned frequently upon swallowing. Still later, over an hour after swallowing the pepper, warmth continued to be felt intermittently in the throat.[48]

Peppermint. One-half cc. of 10% oil of peppermint in olive oil was swallowed in a capsule by B. At first cool sensations in the throat and the upper esophagus were felt. Then there was a very vague warmth accompanied by the typical esophageal ache. Still later the whole throat began to burn with a complex of warmth, 'sting,' ache, and pressure, very well fused, and with cold, not so well fused with the others. The burning feeling is the characteristic feeling of rawness, a sort of 'cold heat.' With it there is a 'drawing' sensation in the region in which 'ice-cream pains' are felt in the head.

IV. The Rectum

The experimental work upon the rectum and intestine was performed upon B only.

1. *Thermal Stimulation*

The sensitivity of the rectum to temperature was studied by means of tube 9 and the apparatus of Fig. 1. Tube 4 was also used in the rectum. The points selected for stimulation were those 5, 10, and 15 cm. respectively from the anus. In being pushed in even as far as 15 cm. the tubes sometimes pressed against the intestinal wall, causing considerable discomfort. At first the experimenter attempted to work at

[48] Meumann's description (*Archiv,* 14, 293f.) does not indicate that the sensations were referred to any region other than that of the stomach.

20 cm., but the difficulty of forcing in a heavy and not too flexible tube led him to give up the attempt. At one time 30 cm. of tube 9 were inserted, with the result that the end of the tube pressed against and distended the body-wall at 62 L 10 (Plate II). The distension was somewhat painful and alarmed the observer, so that, although observations were taken at this point, no attempt was made to repeat them.

The following extracts show the results of the use of tube 9.

0° C. 15 cm. "A slight coolness which spread a little to both sides was felt at the anus. It was very faint and soon disappeared."

0° C. 10 cm. "A thrill of cold that I can hardly localize. I visualized it as several silver threads running across below the surface of the nates. Cold was very intense, but small in area; always keen; lasted a very short time."

0° C. 10 cm. "Several tiny thrills of cold, very difficult to localize; I referred them to the glans and other parts of the penis. Later, after an effort to determine their position, they seemed to lie out in the air away from that part of the body. It seems as if the reason that I can not place them on the body is that, although they seem to be in certain places, the attention to these places (*i. e.*, to the other sensations referred to these places) seems to give a tactual group without the cold sensations, which are somehow different from the tactual."

0° C. 5 cm. B finds "several quite intense, little thrills of cold," which he localizes in the left inguinal region and in the left thigh. He observes again that the tactual sensations which accompany attention to these parts, as well as those that occur when he touches these places with his hand, seem to be peculiarly separate from the cold sensations and unconnected with them. He is inclined to believe that this lack of connection is nothing else than the failure of the two groups to become clear at the same time.

With the water coil of tube 4, B finds, for all positions, a coldness in the region of the anus, which does not occur until the walls of the tube begin to become slightly cool. At 15 cm. he reported a very faint sensation, which he thought at first was going to turn either into cold or into heat. He was not, at any time, able to identify it with confidence, but thought that it might be a weak form of the 'sting' of heat. The same experience occurred at 10 cm. At 5 cm. a slight coolness above the anus was felt.

It appears probable, then, that the rectum is sensitive to cold only in the region of the anus. Cold water, injected into it, gives very intense, bright, cold sensations, which are referred to various places in the region of the perineum. Cold stimulation of the upper rectum produces an indefinite sensation that belongs probably to the pain family, possibly a form of 'thermal pain.'

For warm stimulation 50 cc. of water at 50° C. and at 70° C. were injected through tube 9. It was found that warmth, unlike cold, tended to produce the call to defecation. The call was very marked at 50° C., and at 70° C. it was so violent,—involving intense, griping pains, a general bodily disturbance, and a very strong impulse toward

a motor response,—that it interfered with the introspection. The amount of water in this series was accordingly reduced to 25 cc. The call still remained quite definite, but the pains decreased very much.

At 5 cm. and 50° C., B felt a warmth "quite intense although not heat." It was localized deep in the body, well toward the back and about two centimeters above the coccyx. At the same time, with 25 cc. at 70° B reported a heat, which fused with the muscular sensations involved in the call of defecation, and which turned later into warmth.

At 10 cm. and 50°, B was "surprised at the absence of temperature." At 70°, however, he reported that, after a period of faint pressure, there developed "a sudden burning heat, with pain, followed at once by the call to defecation." Twelve seconds later the heat became warmth, and then gradually faded out during the minute following.

At 15 cm. and 50°, B found no positive temperature, although he remarked that it was very difficult to distinguish between very faint warmth and light pressure. At 70°, warmth was felt in the region of the anus.

In the exceptional case, mentioned above, in which the tube was pushed in to 30 cm. and forced against the body-wall at that point, no temperature sensation was felt for water at 50° C. at the place where the tube ended, although there was general warmth at the anus. Sensations of pressure were definitely referred to the place at which the tube ended. At 70°, besides the warmth at the anus and a general warmth, around the umbilicus, heat from the end of the tube occurred in the same place as the pressures.

With the water coil (tube 4), 25 cc. of water at 50° and at 60° C. were used. A single trial at 70° proved very painful.

At 5 cm. and 50° there was only a very faint sensation which B thought might be either pressure or warmth. At 60° there was pain immediately, and later warmth and heat at the anus.

At 10 cm. and 50°, there was a faint warmth, somewhat delayed, at the anus. For 60° B again hesitated between warmth and pressure, but, as the sensation became more intense, decided in favor of warmth, which appeared to be localized in the scrotum and perineum until he touched those parts. Then the warm sensation seemed to recede farther in. At 15 cm. for both 50° and 60°, warmth was felt after a time at the anus. In the second case, there was also pain and the call to defecation.

We may conclude, then, since warmth is not felt until there has been sufficient time for the tube to become warm, and since in the trials with tube 9 the rectum does not respond with a sensation of warmth except very near the anus, that the lower part of the rectum only is sensitive to temperature. The sensitivity of the anus itself to both cold and warmth was evinced again and again by the fact that cold or warm water, which had been injected and which no longer produced any sensation, felt very cold or warm as it passed the anus in being expelled. The heat felt at 70° and 30 cm. from the anus does not necessarily indicate that the intestinal tract is sensitive to warmth at that place, for 50° did not produce

any temperature there, and the end of the tube was so close to the body-wall that conduction to superficial organs might have been almost immediate with a higher temperature.

The immediate response of the rectum with pain to a temperature of 60°, and the fact that this pain was of the quality of most internal pains, indicate that what rectal sensitivity to thermal stimulation exists is of a painful character.[49]

Warm water in the water-coil did not produce the call to defecation as strongly as did the warm water in direct contact with the rectum. Warmth probably makes the distension of the bowel by the water more effective as a stimulus for defecation, but is inadequate alone.

2. *Mechanical Stimulation*

Mechanical stimulation of the rectum was accomplished by the use of the bladder of tube 11. The apparatus of Fig. 2 was used. For all positions of the tube, the resulting experience was much the same. At first a very faint pressure was felt. The liminal values were approximately 30 cm. of water for the position of 5 cm. from the anus; 24 cm. of water for 10 cm. from the anus; and 20 cm. of water for 15 cm. from the anus. This pressure is described as dull and diffuse and is localized in the region of the rectum; that is to say, B has a visual image of the place, deep in from the back and above the coccyx. Later the call to defecation is produced (at 50 cm. of water for 5 cm. from the anus; at 30 cm. for 10 cm.; and at 32 cm. for 15 cm.). The call is very complex, and gets more so as the pressure is increased. It is produced less easily near the anus. It always involves pressure, colored with a dull ache, similar to the ache-like pressures of the esophagus, and localized in the rectum. These pressures fall into a pattern, which means, for B, movement of the bowels. There are also "general pressures" in the abdomen, which come when the call gets at all intense. They are localized in the region of the umbilicus, but extend well over that portion of the body. They are less ache-like than

[49] These conclusions accord with the original results of Weber (Weber, E. H., Der Tastsinn und das Gemeingefühl, Wagner's Handwörterbuch der Physiologie, iii, 562ff.) and with those of Hertz, Cook, and Schlesinger (*op. cit.*, 485). Head, Rivers, and Sherren, on the contrary, hold that the intestine is sensitive to extremes of temperature (*op. cit.*, 112), and Becher observes that intestinal cold is felt, but localized in the anterior abdominal wall (*Archiv*, 15, 375f.). Meumann insists on the general sensitivity of the intestines, but does not directly consider thermal sensibility (*Archiv*, 14, 310).

the other pressures. Besides the pressures, there are different pains which range from a dull, diffuse, and never more than moderately intense ache to a sharp keen intense pain, which may be either massive or bright (probably an extensive difference). B found it convenient to think of the organic pains as arranged in a two-dimensional manifold, in which an intensive change from 'weak' to 'strong' was paralleled by a qualitative change from 'dull' to 'bright.' Extensive differences, for example those involved in the distinction between fine and heavy, diffuse and clear-cut, occurred independently of the intensive-qualitative relation.[50]

In the call to defecation, all sorts of pains were involved,—bright, intense, fine pains referred to the penis, scrotum, perineum, and abdominal wall, as well as deep, heavier aches within the abdomen. The scrotal pains were usually slightly more massive than the tiny, wiry, shooting pains in the penis and perineum.

We cannot say whether these pressures originate in the rectum itself. Not only is the rectum distended by the rubber bladder, so that adjacent tissues are affected, but the stimulations seem to produce movement over a large portion of the colon, so that the secondary sensational response is widespread.

The pains from the rectum may come from the canal itself or from the peritoneum. The definite ache-like pains, that occurred when the tube was forced against the wall of the rectum, and that could be brought out with very great intensity by pressing the body-wall against the end of the tube at 30 cm., may have come from the intestine, but were more probably caused by the distension of the peritoneum.[51]

3. *Electrical Stimulation*

For electrical stimulation tube 12 was used with the apparatus of Fig. 3.

The rectum is more sensitive near the anus than farther in. The setting of the coil required to produce a just noticeable sensation was 1500 units for 5 cm. beyond the anus and 3750 for 15 cm. Shocks just slightly greater than these liminal values were used as stimuli.

[50] The qualitative classification of organic and cutaneous pains needs to be worked out. A great variety of stimuli adequate to different sorts of pain are indicated in this paper. The writer plans at present to utilize them for a qualitative study.

[51] Our results accord with those of Becher (*Archiv*, 15, 373f.) and Hertz (*op. cit.*, 28ff.).

In quality, the electric shock produced a sensation like muscular pressure. B identified it absolutely with muscular pressure for points well within the rectum. Just beyond the anus, however, it seemed to him to contain more of the brighter quality of cutaneous or subcutaneous pressure. Here there were also traces of an ache, and the whole experience was more or less like an electric shock on the skin. Pain occurred from stimulation well within the rectum only once, and was then described as the "bright, diffuse pain usual in electric shocks."[52]

The sensations resulting from shock were localized fairly correctly for the position just beyond the anus. When the tube was 10 cm. in, they were again felt in about the same position, *i. e.*, deep, and slightly above the coccyx. At 15 cm., however they were referred out into the flesh of the nates. The sensations seemed to extend in a long transverse line at one time across both nates, at another time upon the left natis only, and a third time in a smaller region to the left of the median line.

4. *Chemical Stimulation*

Alcohol. Ten cc. of 30% alcohol, injected with tube 10 at 15 cm. from the anus, resulted at once in stinging pains and the call to defecation, and later in a widespread bodily reverberation, including shivers in the legs and sweat in the chest. Expulsion of the alcohol was exceedingly painful, for it made the anus smart and burn.

Hydrochloric Acid. Ten cc. of 5% HCl introduced at 15 cm. from the anus gave "warm, stinging sensations, in which the sting is bright, somewhat like cutaneous prick." The sensations were localized 5 or 10 cm. within the rectum. Two *per cent.* gave no relevant sensations, although the call to defecation followed shortly.

At 10 cm. from the anus, 5% HCl produced a complex muscular pattern in addition to the warm, stinging sensation described above. Four *per cent.* gave a cool thrill at first and later the stinging sensation. In both cases the call to defecation was very strong indeed, involving pressures all over the abdomen.

A faint sting was felt preceding the call to defecation with 10 cc. of 2% HCl were injected 5 cm. beyond the anus. Expulsion of the acid was very uncomfortable since it produced "raw" sensations in the anus. These sensations were, however, not nearly so intense as those occurring in the expulsion of the alcohol.

Mustard. A mixture of water and mustard (5:1) was injected at 15, 10, and 5 cm. beyond the anus. There were no results beyond a weak call to defecation.

Pepper. Pepper suspended in water (1:100) was introduced at the three usual places. Aside from the sensations involved in the call to

[52] Becher's description of electrical stimulation within the rectum is similar to the present one. He finds dull shock sensations at 20 cm. and bright sensations at the anus (*Archiv,* 15, 374f.).

defecation, which was not intense and occurred in all cases, little thrills of intense cold were experienced. These were referred to the neighborhood of the sphincter and to the anterior surface of the body just above and to the left of the *symphysis pubis*. They occurred immediately and were probably caused by the temperature of the water, which was at 18° C.

Peppermint. Five cc. of oil of peppermint were injected at 15 and 10 cm. from the anus. In the first case, a faint coolness was felt immediately in the rectum. Later, on expulsion of the oil, there were cold burning pains at the anus. The anus felt raw and irritated for some hours afterwards. Apparently the upper rectum is not sensitive to the oil.

V. The Colon

1. *Thermal Stimulation*

An enema of about a quart of water at 50° C. was given in order to see if there were any temperature sensations above the rectum. The usual pressures and pains involved in a violent call to defecation occurred, but there were no temperature sensations referred to any place above the rectum. A second enema at 60° C. produced so much pain that it was necessary to discontinue it before any general warmth had been noted.

An enema of a pint of water at 0° C. resulted successively in cold in the anus, an ache in the penis, an ache-like pressure in the rectum, and finally an indefinite sensation in the region of the umbilicus. This 'indefinite sensation' B describes as "a faint sting, which was possibly cool. It is very much like the sting in 'cold heat,' *i. e.*, the sensations of heat that one gets from a cold stimulus at times during nerve regeneration. It is, however, very much weaker than the cold heat to which I am accustomed."

2. *Pressure*

The various pains and pressures involved in the call to defecation have already been noted in the description of sensations from the rectum (p. 53). The inflation of the whole bowel with air failed to produce anything new. B reported definitely that the pressure was always of a dull muscular variety, always diffuse and never bright. The pains were the usual aches of distension, which get brighter and sharper with increase of intensity (p. 53). A moderate amount of inflation resembled the normal feeling of fullness which ordinarily represents the need for defecation. Greater intensities resulted in typical "belly pains."

Summary

The esophagus is sensitive to warm and to cold stimulation throughout its length. Mild stimuli give rise to sensations which are qualitatively like the sensations of cutaneous warmth and cold. Stimuli of approximately 60° C. give rise to heat, which probably includes a paradoxical cold. Extreme cold or heat results in pain. The temperature sensations are sometimes referred to the throat from lower regions, and the thermal pains are often localized in the head.

Mechanical stimulation, which results in the distension of the esophagus, is sensed at weak intensities as pressure and at greater intensities as pain. Pressure is more readily elicited by rapid than by slow distension. In quality the pressure is like the muscular pressure, and the pain like the deep pain, of the forearm.

The esophagus is everywhere sensitive to bipolar faradic stimulation, and increases in sensitivity toward the pharyngeal end. The experience is qualitatively similar to the pressure-pain complexes of electric shocks upon the periphery.

The esophagus is sensitive to alcohol and hydrochloric acid, but not to oil of peppermint or mustard or pepper in suspension.

The sensations from the esophagus are in general referred either to the region below the sternum or to the throat. The amount and direction of reference are fairly constant for any given position, and the amount is greatest mid-way between the clavicle and the nipples. At this point sensations are referred in either direction, or sometimes in both. Transverse reference is never more than one cm. from the median line. This tendency to localize esophageal sensations upon the soft portions of the body suggests that these portions come by virtue of their mobility to be connected in experience with internal parts.

Cold and warm stimuli in the stomach produce the corresponding sensations, which are identical in quality with cutaneous cold and warmth. It is probable, however, that these sensations do not arise from the stomach itself but from the superficial tissues. Extreme warmth gives rise to pain which may originate in the stomach.

Distension of the stomach gives rise to sensations of dull pressure and, when extreme, of pain.

Electrical stimulation of the stomach gives rise to sensations characteristic of electric shock; the minimal intensities are so great, however, that there is no assurance that the current does not spread to surrounding tissues.

The stomach is sensitive to strong concentrations of alcohol, to oil of peppermint, and to pepper and to mustard in suspension. Hydrochloric acid may produce hunger pains, and in strong concentrations dizziness in the head.

Localization of strong electric shocks within the stomach is quite accurate, much more so than the localization of shocks within the esophagus. The points of reference follow the probable position of the stomach in both the longitudinal and transverse dimensions.

The anus is sensitive to both warmth and cold. The rectum is probably insensitive to both as such; water of 60° C., however, produces pain.

Distension of the rectum produces the call to defecation in all degrees of intensity. The disturbance in this complex experience is so great as to mask any specifically local sensations of pressure that may be set up. In intense degrees the call involves pressures and pains in the abdomen and the genital organs.

The rectum is sensitive to electrical stimulation. It is most sensitive at the anal end.

Alcohol and hydrochloric acid are sensed in the rectum. Oil of peppermint, pepper, and mustard are not. The anus is sensitive to all but the mustard. Hydrochloric acid also produces the call to defecation.

Hot and cold enemata fail to produce thermal sensations in the colon. They do produce pain. Pressures and pains result from distension, but can not be attributed to the intestine itself.